DOCUMENT RESUME

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IDENTIFIERS	*Automotive Fuel Systems; Military Curriculum Project

ABSTRACT

This volume of student materials for a secondary/postsecondary level course in principles of fuel and fuel systems is one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. The purpose of the individualized, self-paced course is to provide the student with a general knowledge of the principles of fuels and the function, operation, and maintenance of components utilized in fuel systems. The course is suggested for use as a subunit in an engine repair or design course. Five lessons cover these topics: introduction to fuels and fuel systems, fuel system components, carburetor circuits, gasoline fuel-injection systems, and multifuel systems. Study texts for each lesson contain objectives, study assignment text material, review exercises, and answers to the exercises. A special section entitled "Fuel Injection" is also included. A course examination is included, but no answers are provided. (YLB)

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MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

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- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
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Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
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405/377-2000

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609/292-6562

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808/948-7834

PRINCIPLES OF FUEL AND FUEL SYSTEMS

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PRINCIPLES OF FUELS AND FUEL SYSTEMS

Correspondence Course 8-4

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Developed by:

United States Army

Development and Review Dates

Unknown

Occupational Area:

Engine Mechanics

Cost:

Print Pages:

269

Availability:

Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Suggested Background:

None

Target Audiences:

Grades 10-adult

Organization of Materials:

Text containing objectives and exercises with programmed answers; supplementary text; and course examination

Type of Instruction:

Individualized, self-paced

Type of Materials:	**No. of Pages:**	**Average Completion Time:**
Principles of Fuels and Fuel Systems		
Lesson 1 – Introduction to Fuels and Fuel Systems	17	Flexible
Lesson 2 – Fuel System Components	25	Flexible
Lesson 3 – Carburetor Circuits	19	Flexible
Lesson 4 – Gasoline Fuel Injection Systems	4	Flexible
Lesson 5 – Multifuel Systems	26	Flexible
Exercise Response List, Answer Sheet	13	
Examination	7	
Fuel Injection (supplementary text)	142	

Supplementary Materials Required:

None

THE CENTER FOR VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

Expires July 1, 1978

Course Description

This course is designed to provide the student with a general knowledge of the principles of fuels and the function, operation, and maintenance of components utilized in fuel systems. It is divided into five lessons.

Lesson 1 – *Introduction to Fuels and Fuel Systems* describes the characteristics of fuel combustion and carburization, and the purpose of fuel system components.

Lesson 2 – *Fuel System Components* covers the construction, operation, and maintenance of components included in conventional fuel systems.

Lesson 3 – *Carburetor Circuits* discusses the purpose and function of basic carburetor circuits; and common troubleshooting and maintenance operations on carburetors.

Lesson 4 – *Gasoline Fuel Injection Systems* discusses the principles of air-fuel injection; and construction, operation, and maintenance of a representative gasoline fuel injection system.

Lesson 5 – *Multifuel System* covers the philosophy of multifuel engines; construction and operation of multifuel systems; and principles of diesel, multifuel, and gas turbine engines.

This course is designed for student self-study and evaluation. Each lesson contains objectives, coded text material, review exercises and answers to the exercises. The answers are programmed so the student has immediate feedback on a correct answer. An incorrect answer refers the student back to the text for further reading, before continuing the exercises. A course examination is available, but no answers are provided. This course can be used as a sub-unit in any engine repair or design course.

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CORRESPONDENCE COURSE
of the
US ARMY ORDNANCE
CENTER AND SCHOOL

ORDNANCE SUBCOURSE NUMBER
403

PRINCIPLES OF FUELS AND FUEL SYSTEMS

JULY 1975

8-4

(IMPORTANT INFORMATION ON BACK COVER)

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CORRESPONDENCE COURSE
# of the
US ARMY ORDNANCE
CENTER AND SCHOOL

ORDNANCE SUBCOURSE NUMBER 403, PRINCIPLES OF FUELS AND FUEL SYSTEMS
(16 Credit Hours)

INTRODUCTION

The Army's ground mobility is based essentially on the reciprocating engine, either spark ignition or compression ignition. This is due to the high degree of development this type engine has received during the past 50 to 80 years; development which has produced flexible, reliable, relatively economical engines.

The reciprocating engine is basically a device for converting the high internal energy of hot gases (produced by the combustion of a hydrocarbon fuel in air) to mechanical energy. This is done by transforming the linear motion of the piston produced by the force of expanding gases to rotary motion of the crankshaft.

Of utmost importance in the operation of an internal combustion engine is the fuel used and the system used to supply the fuel-air mixture to the proper place at the proper time.

This subcourse is designed to provide you with a general knowledge of the principles of fuels and the function, operation, and maintenance of components utilized in fuel systems.

This subcourse consists of five lessons and an examination, organized as follows:

Lesson 1 Introduction to Fuels and Fuel Systems
Scope — Characteristics of fuel, principles of fuel combustion and carburetion, and the purpose of fuel system components.

Lesson 2 Fuel System Components
Scope — Construction, operation, and maintenance of components included in conventional fuel systems.

Lesson 3 Carburetor Circuits
Scope — Purpose and functions of basic carburetor circuits; common trouble-shooting and maintenance operations on carburetors.

Lesson 4 Gasoline Fuel Injection Systems
Scope — Principles of air-fuel injection; construction, operation, and maintenance of a representative gasoline fuel injection system.

Lesson 5 Multifuel System
Scope — Philosophy of multifuel engines; construction and operation of the multifuel system; principles of diesel, multifuel, and gas turbine engines.

Examination

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CHECKLIST OF TEXTS AND MATERIALS FURNISHED

Ordnance Subcourse No 403

July 1975

Only one text is required for this subcourse. It will be returned to the US Army Ordnance Center and School with the final examination answer sheet. Final examination sheets submitted without this text will be returned to the student ungraded. Before you start working on this subcourse check and make certain that in addition to the Study Texts incorporated in this lesson booklet, you have the following text:

ST 9-177, Fuel Injection, January 1973

If the above item is missing, notify us at once.

This subcourse may contain errata sheets. Make sure that you post all necessary changes before beginning.

For your convenience in returning the above text use the postage and fees paid card on the back cover of this subcourse. DO NOT include your answer sheets in the text.

Note. - The following references were used in the preparation of this subcourse.

TM 9-2815-202-34, w/C1	DS and GS Maintenance for Engine, Diesel, Turbocharged, 8V71T	Sep 71
TM 9-2815-210-35, w/C1-5	Engine, Multifuel, LD-465-1 and LDS-465-1	Sep 64
TM 9-2910-200-35, w/C1	Pump, Injector, Fuel, Simmonds, Model SU	Dec 59
TM 9-8000	Principles of Automotive Vehicles	Jan 56

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CORRESPONDENCE COURSE
# of the
US ARMY ORDNANCE
CENTER AND SCHOOL

LESSON ASSIGNMENT

Ordnance Subcourse No 403	Principles of Fuels and Fuel Systems
Lesson 1	Introduction to Fuels and Fuel Systems
Credit Hours	Three
Lesson Objective	After studying this lesson you will be able to: 1. Describe the characteristics of fuels. 2. Describe the principles of fuel combustion and carburetion. 3. Describe the purpose of fuel system components.
Study Assignment	Study the text that follows. It will provide you with information on characteristics of fuel and the principles of fuel combustion and carburetion. It will also provide information on the purpose of fuel system components.
Materials Required	Exercise response list and answer sheet.
Suggestions	Study each illustration as you study the text.

STUDY TEXT

1. INTRODUCTION.

a. Petroleum is the most common source of fuel for modern internal combustion engines. It contains two important elements (carbon and hydrogen) in such proportions that they will burn freely in air and liberate heat energy.

b. No matter how a barrel of crude oil is distilled, various products other than gasoline are produced. In the early days of the petroleum industry when kerosene was the product in demand, distillation was the answer to the problem. However, with today's vehicles, numbered in the millions, the products in demand are gasoline, diesel fuels, and lubricants.

OS 403, 1-P1
July 1975

c. In the processing of oil, several forms of fuel are obtained. Figure 1 shows the approximate percentage of each that is available in a barrel of crude oil.

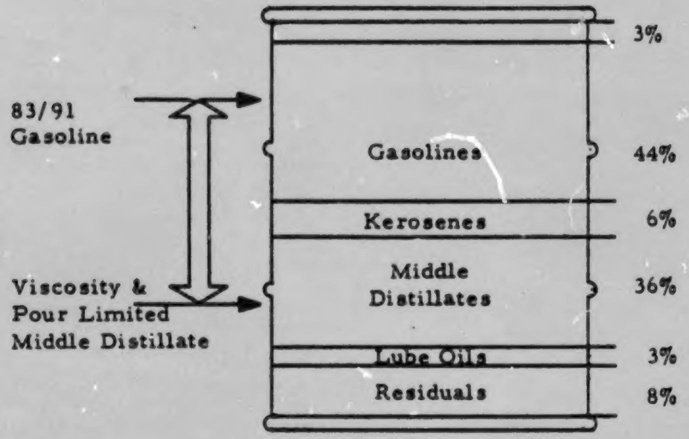

Figure 1. Workable fuel spectrum.

(1) Crude petroleum obtained from underground deposits is first distilled into the various hydrocarbon fractions by heating to the boiling point. The vapors that are separated first form the highly volatile "natural" gasoline when condensed. Next is straight run gasoline, followed by kerosene, distillate fuels, and lubricants, in that order, leaving a paraffin or an asphalt residue, depending upon the basic type of crude petroleum.

(2) Since fractional distillation would not produce the quantity of gasoline needed without an excess of other petroleum products, the heavier, more complex hydrocarbons remaining after the gasoline is removed are reduced or split into lighter and less complex molecules and are reprocessed to produce more gasoline. This reduction (or cracking) is accomplished by either a thermal or catalytic cracking process or both. Decomposition by thermal cracking is done at temperatures from 700° F to 1200° F and pressures of 10 to 15 atmospheres. The catalytic process, using a catalyst to assist in chemical decomposition at similar temperatures and pressures, is more expensive than the thermal process, but produces a higher quality fuel with more desirable antiknock qualities and less sulfur content.

2. CHARACTERISTICS OF FUELS.

a. The greater the hydrogen content of the hydrocarbon molecule, the greater the potential heat energy per unit weight. Petroleum is predominately composed of a mixture of the paraffin, olefin, naphthene, and aromatic families of hydrocarbons. The olefins are not actually found in crude oil; they are formed during refining.

b. Hydrocarbons with a double-bonded carbon atom are unsaturated and, hence, generally more unstable than those that have only single bond saturated carbon atoms. Because of these factors the paraffins have more heat energy per unit weight and are relatively stable.

3. **PROPERTIES OF GASOLINE.** As the power to run the internal combustion engine is derived from the fuel burned, the importance of the energy content of fuel is obvious. Less apparent, perhaps, are the facts that an appropriate amount of air must be mixed with the fuel to support complete combustion where efficiency is of importance and that, often, fuel and air must be present in different proportions required by a wide range of special operating conditions.

a. Volatility is the ease with which the fuel is vaporized under prescribed conditions. To initiate and complete combustion in the spark ignition engine within permissible time limitations, a fuel-air vapor must be present. In cold weather starting or for rapid acceleration, a highly volatile fuel is required. Volatility is also desirable to insure that raw liquid fuel does not wash the lubricant from piston walls and dilute the crankcase oil. After the engine has reached operating temperature, a less volatile fuel is necessary; such a fuel is also desirable for economy in that losses from evaporation will be minimized. Vapor lock in a fuel system occurs when vaporization of the fuel in the fuel lines prevents a sufficient quantity of liquid fuel for satisfactory operation from reaching the carburetor discharge nozzles. Consideration of this problem requires that a fuel must not be so highly volatile as to vaporize readily from ambient or radiated engine temperatures. From these requirements it can be seen that a carefully blended gasoline falling between the extremes of volatility is required for current spark ignition engines.

b. Stability is the ability of a fuel to retain its initial physical and chemical properties. This is essential because of the relatively long periods of storage after production and the metals and gases to which the fuel will be exposed before being used. Olefins and diolefins (chemical properties of gasoline) tend to oxidize, especially when exposed to sunlight and high ambient temperatures. This oxidation causes a gum formation, not soluble in gasoline, which lodges in fuel lines and carburetor passages, on valves, and on the surfaces of the combustion chamber, increasing engine deposits and lacquering of the cylinder walls. Chemical reactions with other elements or with themselves will nullify the effect of careful blending and antiknock additives. Careful selections of the base stock components, removal of sulfur compounds, tars, resins, and diolefins by chemical treatment, and the addition of chemical inhibitors are methods used to promote stability.

4. **OCTANE RATINGS.** The ability to resist detonation is such an important fuel property that it is desirable to have some standard method of measuring this characteristic. For many years this measurement has been accomplished by use of a standard test engine in which the performance of a fuel is compared to the performance of various mixtures of iso-octane and normal heptane. The results are reported as the octane number of the fuel.

a. To establish a common reference level upon which to base octane rating, a standard fuel is used in a standard test engine which is run under specified conditions. Engine construction, fuel composition, and operating conditions are specified by the American Society for Testing Materials. The engine used is designed so that compression ratio may be varied. For this first step of the test, however, the compression ratio is maintained at a specified value. Knock intensity of the standard fuel is recorded under these conditions. This intensity is measured through a pressure-sensitive device in the cylinder that closes an electrical circuit that, in turn, deflects a knock indicator needle in proportion to the intensity of knocking. Next, the test engine is run on the fuel whose octane rating is to be determined. The compression ratio of the test engine is varied until knock intensity is the same as that of the test engine running on standard fuel. Keeping the same compression ratio, by trial and error, the blend of iso-octane and normal heptane that will give again the same knock intensity is determined. The percentage by volume of iso-octane in this blend is the octane number or rating of the fuel.

b. Iso-octane has great resistance to detonation but normal heptane causes the engine to knock. So, the higher the octane rating of the fuel, the greater is its resistance to detonation. When the unknown fuel has less tendency to knock than pure octane, the rating is reported as 100 plus the number of milliliters of tetraethyl lead per gallon that must be added to the octane to achieve the matching mixture.

c. Fuels for different purposes demand different conditions of testing if test results are to be significant. Several methods of testing and of reporting test data have been developed. The basic methods are research, motor, aviation, supercharge, and AN performance number (a method of reporting performance data). Only the first two methods are used for rating fuels for automotive engines. The other methods are used for aircraft purposes. Test conditions for the motor method are more severe than in the research method. For this reason, the research method leads to higher octane ratings for a given fuel and is the method whose results are most frequently quoted in advertisements.

d. There are limitations to the octane rating of a fuel. It is only one of the characteristics of importance in the selection of a motor fuel. All properties of fuels must be considered to obtain fuel suitable for given operating conditions. A fuel may have good antiknock qualities and be so deficient in another respect to preclude its use in an automotive engine. Fuel having the same octane number may give dissimilar performance when operated in different engines or even in the same engine.

e. From this discussion, it can readily be concluded that paying a premium for fuel of higher octane rating than a particular engine requires is a waste of money.

5. CHEMISTRY OF COMBUSTION.

a. Complete combustion. The term "complete combustion" means combustion in which the fuel is completely changed to carbon dioxide and water; that is, there is no fuel remaining nor is there any carbon in the form of free carbon or carbon monoxide.

b. Normal combustion.

(1) It would be desirable to have combustion initiated and completed at top dead center. This would give the constant volume heat addition and the ideal output of the air standard cycle. Constant volume heat addition is impossible in the actual cycle, however, because of the definite period of time it takes to initiate and complete combustion.

(2) At the end of the compression stroke on engines having a 7 to 1 or 8 to 1 compression ratio, the temperature of the fresh charge of fuel reaches about 700° to 800° F before combustion is initiated. Self-ignition temperature of a homogeneous fuel-air mixture is approximately 900° F under quiescent (quiet or still) conditions. The arc of electrical energy released across the electrodes of the spark plug must provide sufficient release of heat to raise the temperature of the mixture in and near the spark gap above the mixture's self-ignition temperature. Since the actual charge is nonhomogeneous (not the same in structure) and a high turbulence exists, the temperature in the spark gap is approximately 4000° F, which insures ionization and the beginning of dissociation of the fuel molecules. Engines with higher compression ratios must use fuels with correspondingly higher self-ignition temperatures.

(3) Combustion does not begin, however, at the instant the spark jumps the gap. A period of time lapses before the fuel and air molecules are energized by the electrical heat energy to a level where the dissociation reaction of the hydrocarbon and the subsequent combining with oxygen are self-sustaining. Once dissociation of the fuel and combining of the carbon and hydrogen with oxygen has begun, the release of heat energy from this initial reaction is sufficient for propagation of further similar reactions. The resulting flame front moves across the combustion chamber in a ragged spherical front. This advancing flame front is similar to waves or ripples traveling outward from a pebble thrown in a pool of water. As an example, consider a long tube containing a fuel and air mixture. If the mixture is ignited, the flame front will advance about 3 feet per second. This is far too slow for high speed, high output engines. Flame speeds in modern powerplants vary from 20 to over 100 feet per second, depending upon the operating conditions. In keeping with the flame front, temperatures must be considered because they become higher as the flame progresses across the combustion chamber. The cylinder temperature becomes higher from the heat liberated during combustion as the flame front progresses across the combustion chamber. Temperature of the burned gases also increases with the increase in chamber pressure. It can be deduced that the combustion chamber pressure rise is gradual, that the temperature and pressure of the last portions to burn (the end gas) is much higher than that of the initial fresh charge, and that the temperature at the spark plug is higher after complete combustion than it was when burning was initiated.

c. Irregular combustion. No discussion of fuels can be complete without an explanation of the several forms of irregular combustion. The importance of understanding the nature, causes, and effects of irregular combustion can hardly be overestimated. Combustion chamber design is dictated to a large extent by the necessity for avoiding abnormal combustion.

(1) The speed of the flame that spreads out from the spark plug in the spark ignition engine is much greater than the mean speed of the piston. For flame speeds mentioned earlier (20 to 100 feet per second) mean piston speeds are about 15 feet per second. Of course, when combustion takes place, the piston is near top dead center and its instantaneous speed is even less. As a result, the flame front rapidly overtakes the piston and, in doing so, heats the unburned fuel-air mixture ahead of it. Temperature and pressure in the unburned fuel-air mixture ahead of the flame front are raised as previously discussed. The result of this may be auto-ignition of the unburned fuel. When the unburned fuel self-ignites, it is consumed with extreme rapidity. Associated with this rapid combustion is a very high rate of pressure rise and an audible ping or knock. This irregular combustion is called detonation, which is a result of the fuel used, the mechanical design of the engine, and the conditions under which the engine is operated.

(2) Contrary to popular belief, detonation in itself does not produce a significant loss in thermal efficiency. Undesirable effects chargeable directly to detonation are:

(a) Overheating of combustion chamber parts adjacent to the last part of the mixture to burn.

(b) A severe stressing of engine parts due to the rapid rate of pressure rise.

(c) Failure of engine components under severe detonation conditions.

(d) Objectionable knocking sound.

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(3) For the reasons given above, detonation must be avoided at all costs. In most spark-ignition engines, detonation of present day fuels is the major factor in determining the maximum practicable compression ratio.

(4) The ignition of the combustion chamber charge before the spark occurs is known as preignition. Its cause may be attributed to any of the following:

(a) Overheating of the spark plugs.

(b) Hot exhaust valves.

(c) Burning carbon deposits.

(d) Incandescent gases from previous cycles.

(5) Preignition leads to progressive overheating of valves and spark plugs, which may result in failure of the engine. While the presence of preignition may lead to detonation, or vice versa, the two may exist independently and definitely are not the same event. Preignition has the same effect as excessive spark advance; that is, it reduces the efficiency of the engine, increases engine temperatures, and increases cylinder pressure.

6. FUEL-AIR RATIO REQUIREMENTS.

a. General. It is a generally established fact that the best mixture for normal gasoline engine operation is approximately 15 parts of air to 1 part of fuel. However, anyone who has driven a car or operated a machine that is powered by a gasoline engine knows that normal operation will not always satisfy the requirements placed on the engine. At idling speeds, during acceleration speeds, and during times that additional power is required, the fuel-air mixture must be varied to best satisfy the particular situation. Also, the 15:1 ratio is based on a typically blended fuel and all fuels are not alike.

b. Ratio for maximum power. When additional power is required from an engine for such purposes as climbing hills, starting from a standstill, accelerating for passing, or for holding high speeds, a richer fuel-air mixture is needed. In this case a greater volume of fuel and air enters the cylinders with the volume of fuel increasing more rapidly than that of the air. Each engine has a point where it will burn all the fuel-air mixture that enters the cylinder. Any volume above this amount will be wasted by going out of the exhaust or, worse yet, draining down into the crankcase. The power ratio, approximately 12:1 or 13:1, will provide from 5 to 7 percent more power at an expense of about 20 percent more fuel.

c. Ratio for economy. Maximum economy of the fuel-air mixtures is accomplished when all the fuel in a cylinder burns. Because it is impossible to have the perfect fuel-air mixture present in all areas of the cylinder at the exact instant of ignition, economy is gained by reducing the ratio of fuel and air a slight amount from the optimum of 15:1. Dependent on the throttle position, this ratio does reduce the amount of fuel wasted.

d. Ratio for idling. When an engine is idling, the vacuum of the intake manifold is very high because of the closed throttle position in the carburetor. This allows very little air to be mixed with the fuel. The mixture ratio for idling is therefore much richer than the power ratio and is approximately 10:1.

e. Excessively rich ratios. There is a point at which engines will cease to operate correctly when the fuel-air mixture is too rich; if the richness is continued, combustion will not take place. During operation this condition becomes noticeable by a pattern of misfiring or power surging. When enough of the cylinders are affected, engine operation will cease completely, due to what is commonly called flooding.

f. Excessively lean mixtures. When fuel-air ratios are too lean, they will not burn in a spark ignition engine. When mixtures approaching the too lean condition are introduced in an engine cylinder, it will cause backfiring through the carburetor. This is due to the extremely slow burning time of the mixture, whereby it will still be burning when the intake valve opens for the next cycle and ignite the mixture in the manifold. Lean mixture may also cause spasmodic misfirings whereby the mixture will be exhausted into the exhaust system. The slow burning of the mixture that has been ignited could then cause a burning mixture to be exhausted also and cause backfiring.

g. Cold engine starting. When starting a cold engine, some of the fuel remains as a liquid or recondenses on the cylinder wall or piston. Because the mixture is not vaporized at this time, care must be taken to prevent flooding. The mixture requirements for cold starting vary in accordance with the temperature and the condition of the engine and ignition systems. Fuel-air mixtures ten times the normal requirement are not uncommon for cold starting.

LESSON EXERCISE QUESTIONS

Instructions for use of the answer sheet:

1. The procedure by which you will answer the exercise questions in this subcourse is probably new to you. The information is presented in a programed instruction format where you immediately know whether or not you have answered the questions correctly. If you have selected an incorrect answer, you will be directed to a portion of the study text that will provide you with additional information.

2. Arrange this subcourse booklet and your answer sheet so that they are convenient. Each exercise question has three choices lettered a, b, and c. Your answer sheet has three groups of numbers for questions 1 through 200. The numbers indicated for each question represent the a, b, or c choices. The exercise response list is inclosed with this subcourse. It contains a listing of 3-digit numbers in numerical sequence. Each number is followed by a response that either reinforces a correct answer or gives you additional information for an incorrect answer.

3. To use this system proceed as follows:

a. Read the first exercise question and select the choice you think answers the question correctly. Go to the question 1 area of your answer sheet and circle the 3-digit number that corresponds with the choice you selected.

b. After you have identified the 3-digit number, locate it in the exercise response list. If you selected the right choice, the first word of the response will be "CORRECT." This tells you that you have answered the question correctly. Read the rest of the response which tells why your choice was correct and then go to the next question.

c. If the word "CORRECT" is NOT the first word of the response, you have selected the wrong answer. Read the rest of the response and then turn to the area in your study text that is mentioned. There you will find the information necessary for you to make another choice. Be sure to read all of the response because it will help you select the correct answer and it also provides more information. Line out the incorrect 3-digit response on your answer sheet.

d. After you have reread the reference, select another answer and circle the 3-digit response for that choice. Again check the number of this second choice with the response list to see if your choice is now correct and to obtain more information about your choice. If your second choice is still not correct, line out the 3-digit response on the answer sheet and continue until the correct answer is selected. When you have answered all of the questions in an exercise, count the number of lined out responses and see how well you did.

4. You will notice that the lesson exercise question numbers continue consecutively from lesson to lesson. This allows you to use one answer sheet for the entire subcourse.

5. After you have finished the exercise questions for all lessons, fold and seal the answer sheet so that the USAOC&S address is on the outside. Drop the answer sheet in the mail so the school will know you have completed the study portion of the subcourse and are now ready for the examination.

EXERCISE

1. What elements are contained in petroleum in such quantities as to make it burn freely?

   a. Hydrogen and oxygen
   b. Carbon and hydrogen
   c. Helium and nitrogen

2. Which vapors are separated first when crude oil is distilled?

   a. Kerosene
   b. Gasoline
   c. Heavy distillate

3. Decomposition by thermal cracking is done at temperatures of

   a. 400° F to 600° F.
   b. 700° F to 1200° F.
   c. 1300° F to 1500° F.

4. What refining process produces a higher quality fuel with less sulfur content?

   a. Thermal cracking
   b. Fractional cracking
   c. Catalytic cracking

5. What determines the potential heat energy per unit weight of the hydrocarbon molecule?

   a. Percentage of hydrogen content
   b. Amount of oxygen content
   c. Percentage of carbon content

6. What is formed in crude oil during refining?

   a. Paraffin
   b. Naphthene
   c. Olefin

7. Why is high volatility in fuel desirable during cold weather?

   a. Helps reduce crankcase dilution
   b. Reduces manifold evaporation
   c. Helps reduce the chance of vapor lock

8. What can be added to fuel to promote stability?

   a. Inhibitors
   b. Diolefins
   c. Resins

9. What chemical properties of gasoline tend to oxidize when exposed to sunlight and high ambient temperatures?

   a. Resins and asphalt
   b. Sulfur and tars
   c. Olefins and diolefins

10. What reference fuel has a great resistance to detonation?

   a. Heptane
   b. Tetraethyl
   c. Iso-octane

11. What test method used to determine the octane rating of fuels developed for automotive engines produces the truest results?

   a. Supercharge
   b. Motor
   c. Research

12. What is the approximate self-ignition temperature, in degrees Fahrenheit, of a homogeneous fuel-air mixture under motionless conditions?

   a. 700
   b. 800
   c. 900

13. What is the major factor in determining the maximum practicable compression ratio in most spark ignition engines?

   a. Detonation of present day fuels
   b. Brake horsepower availability
   c. Consumption of present day fuels

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7. PRINCIPLES OF CARBURETION.

a. Composition of air. Air is composed of various gases, mostly nitrogen and oxygen (78 percent, by volume, of nitrogen; 21 percent, by volume, of oxygen). These gases are, in turn, made up of tiny particles called molecules. All substances whether solid, liquid, or gas are made up of molecules. In solids, such as iron, the particles are held closely together so that they seem to have no motion. In liquids, the molecules are not held together tightly, so they can move with respect to each other. Liquid can flow. In gases, there is less tendency for the molecules to hold together; therefore, the molecules can move quite freely. The molecules of a gas are attracted to the earth by gravity, or by their weight. It is the combined weight of the countless molecules in the air that we feel as atmospheric pressure.

b. Evaporation. When a liquid changes to a vapor (gas), it has evaporated. When this happens, molecules of the liquid move from the liquid into the air. As this continues, the liquid disappears from its container and appears as vapor in the air. The rapidity of evaporation varies with a number of factors. One of these is the volatility of the liquid. Others include temperature, total pressure above the liquid, and amount of liquid that has already evaporated into the air above the liquid (degree of saturation).

(1) Liquid consists of molecules that move about. As they do so, they collide with each other. If a molecule happens to be moving upward rapidly enough, it will be able to jump clear of the liquid. As the molecules of liquid continue to do this, the liquid evaporates.

(2) At higher temperatures, molecules move faster. This is true regardless of whether the molecules are in a solid, liquid, or gas. At low temperatures, the molecules move more slowly. When a liquid is heated, there are many fast-moving molecules escaping from the liquid. In other words, the rate of evaporation increases. This action can be easily seen in the process of boiling water, where the molecules are moving so rapidly they escape in large numbers and in a violent manner.

(3) When there is little pressure above the liquid, the molecules can escape from the liquid easily. When the pressure is high, it is more difficult for the molecules to escape and the rate of evaporation is decreased. Some of the molecules from the liquid collide with molecules of the air above and are often knocked back into the liquid.

c. Atomization. Atomization is the breaking up of a liquid into very tiny particles or globules. Atomization helps to turn a liquid into a vapor. If a spoonful of gasoline were put into a pan, it would take several seconds for it to evaporate; the length of time depending on temperature, volatility, and pressure. However, if a spoonful of gasoline were put into an ordinary spray gun, of the type used to spray insecticides, the gasoline would be broken into a fine mist when operating the gun and would turn almost instantly into vapor. The reason for this is that a much greater area of the liquid is exposed to air when the gasoline is atomized. Evaporation takes place from all surfaces and increases with greater surface area.

d. Venturi effect. A venturi is an hourglass-shaped restriction. In the carburetor, a venturi is placed in the air horn through which the air must pass on its way to the intake manifold and the engine cylinders. The purpose of the venturi is to create a partial vacuum (low-pressure area) at the outlet of the nozzle, which will permit atmospheric pressure on the surface of the gasoline in the float bowl to force the gasoline out through the nozzle. This gasoline is then sprayed and atomized in the passing air to form the fuel-air mixture. It may seem like a contradiction to say that the restriction produces a vacuum, but let us examine the action of the air molecules as they pass through the venturi (fig 2). As they enter the horn on the left, they move toward the venturi at uniform speed. However, as they approach the venturi, they must increase their speed if all molecules are to get through. That is, with the restriction, the molecules must move faster to get through. The increased speed of the molecules produces a decrease in pressure (a partial vacuum). It is a known fact that the total energy of all things in nature remains constant, but energy can change from one form to another. Rubbing two sticks together to produce fire is an example of motion (one form of energy) being converted into heat (another form of energy). Also, if one form of energy increases, one or more other forms of energy must decrease, since the total energy remains constant. Thus, the increased speed of the molecules in a venturi produces a decrease in pressure; the increased speed results in a decrease in temperature. Evaporation of the fuel further decreases the temperature. Atmospheric pressure is admitted to the bowls and presses downward on the liquid. Since there is less than atmospheric pressure in the venturi, the liquid is forced up into the tube. In a carburetor, the atmospheric pressure on the fuel in the bowl (fig 3) forces fuel through the fuel nozzle and into the high speed stream of air where it is atomized.

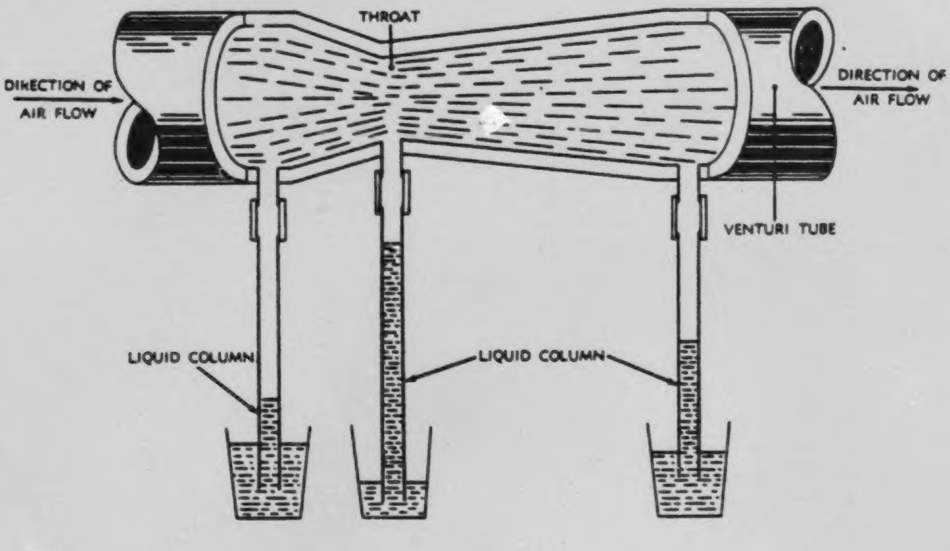

Figure 2. Action of air flowing through a venturi tube.

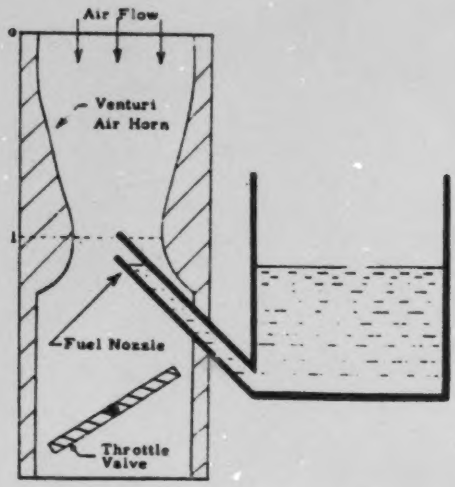
Air Flow
0
Venturi
Air Horn
1
Fuel Nozzle
Throttle
Valve

Figure 3. A simple carburetor.

8. FUEL SYSTEM COMPONENTS (SPARK IGNITION ENGINES). The fuel system (fig 4) supplies a combustible mixture of gasoline and air to the engine cylinders and consists of the following components:

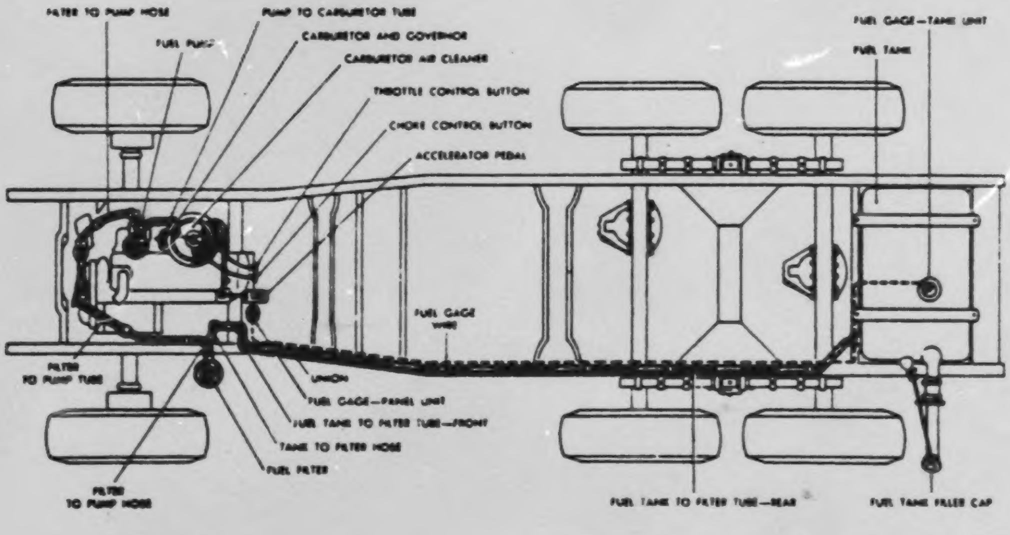
FILTER TO PUMP HOSE
FUEL PUMP
PUMP TO CARBURETOR TUBE
CARBURETOR AND GOVERNOR
CARBURETOR AIR CLEANER
THROTTLE CONTROL BUTTON
CHOKE CONTROL BUTTON
ACCELERATOR PEDAL
FUEL GAGE—TANK UNIT
FUEL TANK
FUEL GAGE WIRE
FILTER TO PUMP TUBE
UNION
FUEL GAGE—PANEL UNIT
FUEL TANK TO FILTER TUBE—FRONT
TANK TO FILTER HOSE
FUEL FILTER
FILTER TO PUMP HOSE
FUEL TANK TO FILTER TUBE—REAR
FUEL TANK FILLER CAP

Figure 4. Gasoline engine fuel system components.

a. A fuel tank to store gasoline in liquid form. Fuel tanks are fabricated in various sizes and shapes to conform with the item of equipment on which it is used.

b. Fuel lines, hollow metal tubes, that allow the liquid fuel to flow from the storage tank to other components of the system.

c. A fuel gage, though not necessary for engine operation, used as a signaling device to indicate to the operator the amount of fuel in the storage tank.

d. A fuel filter designed to remove dirt and foreign particles from the liquid gasoline.

e. A fuel pump, a mechanically or electrically operated device to pump gasoline in liquid form from the fuel tank through the fuel lines and into the carburetor.

f. A carburetor to mix the liquid gasoline with air. In this mixing process, the liquid gasoline is partially vaporized (turned to vapor). The carburetor also serves as the throttle to control the speed of the engine.

g. An air filter, normally mounted on the carburetor, to remove dust particles from the air as it passes through on the way to the engine.

h. A degasser to shut off the fuel supply to the carburetor idle system when there is a high intake manifold vacuum during deceleration. This device is generally used with tracked vehicle engines where magnetos are used and it is the most effective means of stopping the engine.

i. Two types of manifolds—intake and exhaust. The intake manifold is a series of pipes or passages through which the air-fuel mixture from the carburetor is directed to the engine cylinders on the intake stroke. After the mixture is burned and the piston is moving up within the cylinder on the exhaust stroke (exhaust valve now open), the burned gases are discharged into the exhaust manifold. From there they pass through pipes, through the muffler (which muffles the noise), and through the tailpipe into the atmosphere.

j. A primer system, used with some vehicles to enrich the fuel-air mixture for starting. The system incorporates a hand pump, actuated by the operator, that sprays fuel directly into the intake manifold.

k. An engine governor to prevent overspeeding of the engine and help to reduce engine wear. There are several types of governors, but they all produce essentially the same result; that is, they cut down, or limit, the amount of fuel-air mixture into the engine when engine speeds tend to go beyond specified limits.

l. A fuel-air distributor impeller or diffuser system is used on radial engines or on engines with many cylinders. This system's function is to provide a more uniform distribution of fuel-air mixture to the cylinders.

9. **FUEL SYSTEM COMPONENTS FOR COMPRESSION IGNITION INTERNAL COMBUSTION ENGINES.** The fuel system (fig 5) supplies fuel and air in correct amounts and proper sequence to permit proper functioning of the compression ignition engine. It consists of the following components:

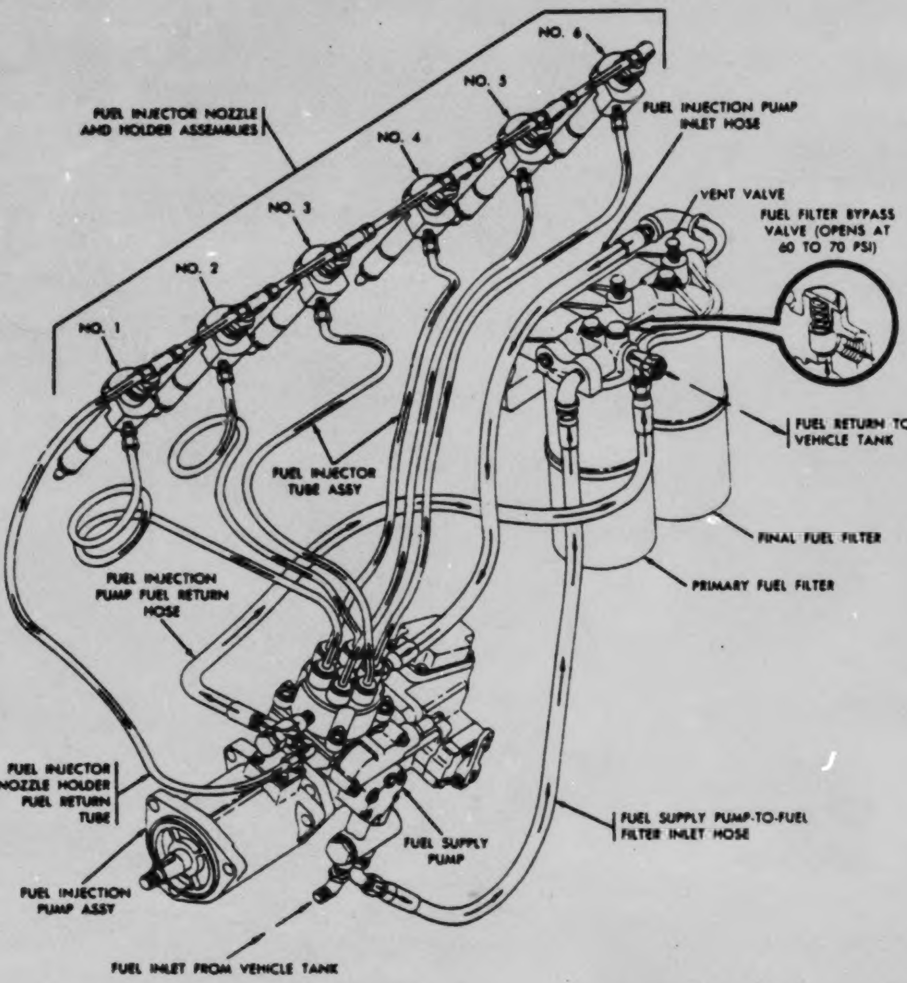
NO. 6
NO. 5
FUEL INJECTOR NOZZLE AND HOLDER ASSEMBLIES
FUEL INJECTION PUMP INLET HOSE
NO. 4
NO. 3
VENT VALVE
FUEL FILTER BYPASS VALVE (OPENS AT 60 TO 70 PSI)
NO. 2
NO. 1
FUEL RETURN TO VEHICLE TANK
FUEL INJECTOR TUBE ASSY
FINAL FUEL FILTER
PRIMARY FUEL FILTER
FUEL INJECTION PUMP FUEL RETURN HOSE
FUEL INJECTOR NOZZLE HOLDER FUEL RETURN TUBE
FUEL SUPPLY PUMP-TO-FUEL FILTER INLET HOSE
FUEL SUPPLY PUMP
FUEL INJECTION PUMP ASSY
FUEL INLET FROM VEHICLE TANK

Figure 5. Compression ignition fuel system components.

a. A fuel supply pump that is part of the fuel injection pump assembly. This pump takes fuel from the vehicle fuel supply tank and delivers it under pressure to the primary and final fuel filters. Fuel is pumped through the fuel filters to the fuel injection pump. The injection pump then meters and distributes the fuel to the proper fuel injector nozzles and holder assemblies in firing order sequence.

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b. Primary, secondary, and final fuel filters to insure that clean fuel is delivered to the fuel injection pump, which is important in maintaining troublefree engine operation. The secondary and final fuel filters are identical and have interchangeable and replaceable elements. The primary and secondary fuel filters remove most of the foreign material from the fuel. The final fuel filter removes any remaining foreign material which has escaped the filtration of the secondary fuel filter.

c. A fuel injection pump assembly that is driven by the engine camshaft gear. This pump is used to supply pressurized fuel to each individual fuel injector nozzle and holder assembly in sequence with the engine firing order.

d. In a 6-cylinder engine, there are six fuel injector nozzle and holder assemblies used to inject fuel into the combustion chambers. The injector nozzle and holder assemblies are sealed against leakage by copper gaskets. The nozzle and holder assemblies are interconnected by fuel return tubes to provide a path for the return of excess fuel back to the fuel tank. The nozzle and holders are designed to provide adjustment to allow proper opening pressure and spray pattern for economical engine operation and proper performance.

e. A fuel supply pump-to-fuel filter inlet hose, fuel injection pump inlet hose, and fuel injection pump fuel return hose which are flexible rubber composition hoses or plastic tubing. The six fuel injection tubes are soft annealed steel tubing which are subject to high fuel pressure operation. The tubes are the same length and are preformed to convey fuel from the fuel injection pump head to each individual fuel injector nozzle and holder assembly. The fuel injector nozzle holder fuel return and fuel excess tubes are made of a nylon or plastic composition.

f. A turbosupercharger to increase the velocity and pressure of the intake air, thereby forcing a greater volume of air into the combustion chambers as compared with a nonsupercharged engine. This higher volume of air, resulting in a more constant fuel air ratio, increases engine power. A turbosupercharger, which is essentially an exhaust gas-driven blower, utilizes the kinetic energy usually lost in the exhaust gases to compress air into the cylinders. The exhaust gases from the engine enter the turbosupercharger and are forced around the turbine housing radially inward, through a nozzle ring. The exhaust gases drive the turbine wheel which, in turn, drives the compressor wheel, since both wheels are fixed onto a common shaft. Air enters at the center of the compressor wheel and flows radially outward through a tangential outlet on the outside of the compressor housing and enters the intake manifold. The exhaust gases that were the contributing force to drive the supercharger unit are expelled from the turbosupercharger into the vehicle's exhaust system.

Note. - Answer the questions below.

14. What action is taking place when the molecules of a liquid move from the liquid into the air?

    a. Atomization
    b. Evaporation
    c. Condensation

15. When liquid is broken into tiny particles or globules, it is

    a. vaporized.
    b. atomized.
    c. evaporated.

16. What is a function of the venturi in the air horn?

    a. To reduce the molecular speed at the nozzle
    b. To increase the fuel temperature for atomization
    c. To create a partial vacuum at the outlet of the nozzle

17. What forces the gasoline from the fuel bowl through the nozzle in a simple carburetor?

    a. Atmospheric pressure
    b. Partial vacuum
    c. Manifold pressure

18. What spark ignition fuel system component is employed in a radial engine but is NOT required in a 6-cylinder in-line engine?

    a. Hand-actuated primer pump
    b. Degasser
    c. Fuel-air distribution impeller

19. What type of material is used to fabricate the injection tubes in a multifuel engine?

    a. Rubber composition
    b. Nylon composition
    c. Soft steel

20. Why is a turbosupercharger used with a compression ignition engine?

    a. Reduce volume of fuel burned
    b. Burn excess exhaust gases
    c. Increase engine power

CORRESPONDENCE COURSE
# of the
US ARMY ORDNANCE
CENTER AND SCHOOL

LESSON ASSIGNMENT

Ordnance Subcourse No 403	Principles of Fuels and Fuel Systems
Lesson 2	Fuel System Components
Credit Hours	Two
Lesson Objective	After studying this lesson you will be able to: 1. Describe the construction of the components in conventional fuel systems. 2. Explain the operation of components in conventional fuel systems. 3. Describe the maintenance of components in conventional fuel systems.
Study Assignment	Study the text that follows. It will provide you with information on the construction, operation, and maintenance of components in conventional fuel systems.
Materials Required	Exercise response list and answer sheet.
Suggestions	Study each illustration as you study the text.

STUDY TEXT

1. INTRODUCTION. Fuel system components are responsible for supplying the correct amounts and mixtures of fuel and air to the engine cylinders. To accomplish this function the system must include a fuel container, a means of delivering fuel from the container to a fuel and air mixer, a device for metering the fuel-air mixture, and tubes or conduits for conveying the fuel or fuel mixture to the proper place. In addition to the primary components mentioned above, most fuel systems include filters to assure that water and sediment are removed from the liquid fuel and that dust is removed from the air. To aid the operator, a visual device indicates the amount of fuel that is in the container. Each component has a specific function to perform and any unsatisfactory performance of that function results in inefficient engine performance.

2. DESCRIPTION AND OPERATION OF FUEL SYSTEM COMPONENTS.

a. Fuel tanks. The fuel tank is a storage tank and may be located almost anywhere on the equipment. On most passenger cars and on some trucks, the gasoline or fuel tank is located at the rear of the vehicle. The location of the tank is not too important, if it is out of the way, as a fuel pump will force the gasoline to the carburetor. If the tank is higher than the carburetor, gravity eliminates the need for a fuel pump.

(1) A cutaway drawing of one type of fuel tank is shown in figure 1. Tanks for fuel are usually made of thin-gage metal covered with an alloy plating to prevent rust and corrosion. A fuel tank has a filler spout or pipe for filling the tank. The spout or pipe is covered with a filler cap to keep out rain and dirt. Usually these caps are not airtight as air must enter the tank as fuel goes out. On vehicles designed to ford streams, the filler cap is both airtight and watertight. In this type vehicle the tank is vented to the atmosphere by a special vent pipe that opens somewhere above the gas tank where water cannot enter but air can. The outlet pipe, fitted for the fuel line connection, may be located almost anywhere on the tank, but it extends into the tank to about one-half inch from the bottom. This prevents dirt or sediment in the bottom of the tank from entering the fuel line. Baffle plates in the tank reinforce it and prevent splashing of the fuel. The baffles have holes to allow the fuel to seek its own level in the tank. The float mounted in the tank actuates a lever to give a reading as to the amount of fuel in the tank.

(2) Some vehicles have more than one fuel tank. When there is more than one, they are interconnected by fuel lines and each has a shutoff valve. Some tanks may have a special kind of rubber lining so that if they are punctured they will seal themselves to prevent the fuel from leaking out.

b. Fuel lines and fittings.

(1) Fuel lines are located between the fuel tank and fuel filter, between the filter and fuel pump, between the pump and carburetor, and frame to engine flexible line. Each fuel line is a rather small metal tube. It is usually made of copper or rust-proofed steel tubing and it is connected to each part it joins by fittings. These fittings make it possible to easily remove and replace the parts of the fuel system which are connected by the fuel lines.

(2) Figure 2 shows two typical kinds of fittings: one is the flare-type and the other is the compression ring-type. The part of the fitting that fits into the unit has tapered pipe type threads. The other end of the fitting may have special threads. In the compression ring type the compression ring is loose on the pipe until after it has been tightened down once in use. There are many kinds of fuel and oil line fittings but most of them are similar, at least in principle, to the types pictured.

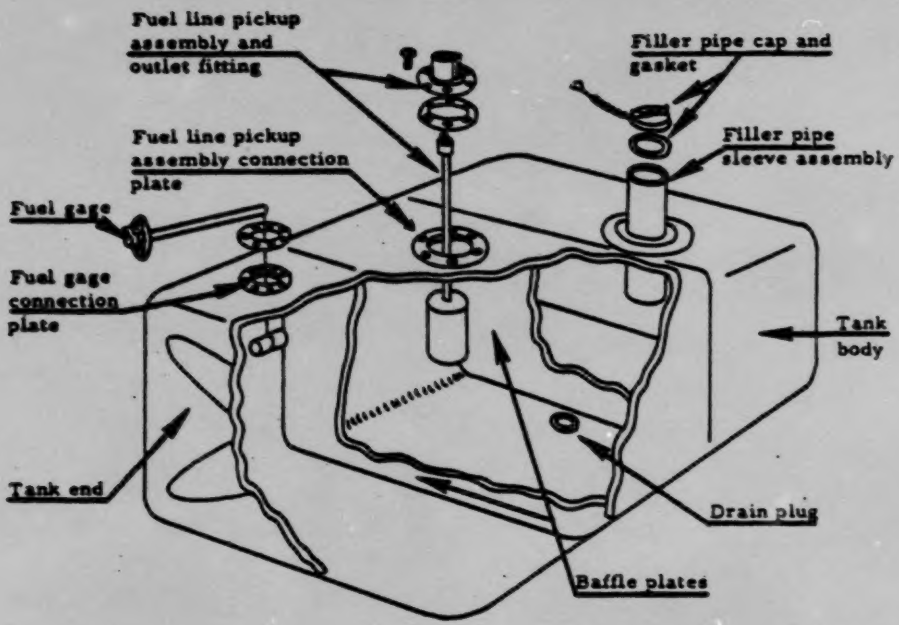

Fuel line pickup assembly and outlet fitting
Filler pipe cap and gasket
Fuel line pickup assembly connection plate
Filler pipe sleeve assembly
Fuel gage
Fuel gage connection plate
Tank body
Tank end
Drain plug
Baffle plates

Figure 1. Fuel tank.

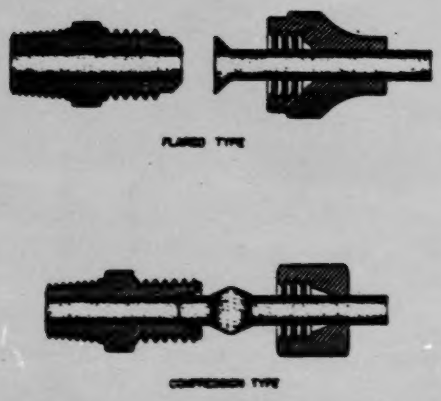

FLARED TYPE
COMPRESSION TYPE

Figure 2. Fuel line fittings.

c. Fuel filters. The fuel filter may be located anywhere between the fuel tank and carburetor. Usually, it is located between the fuel tank and fuel pump.

(1) The purpose of the filter is to prevent water, dirt, and other foreign materials from passing through the carburetor and into the combustion chamber.

(2) Another type of filter is a separate unit made of a series of disks in layers. The disks are in a bowl which acts as a settling chamber. Figure 3A illustrates this type filter. Fuel enters the filter at the top inlet connection and fills the bowl. To go out the outlet, the fuel must pass between the disks in the strainer assembly. Since the disks are close together, the dirt and water cannot pass between them and are deposited on the outer rim of the disks. Water cannot pass through when it is present in gasoline because it forms globules that are too large to pass between the disks. This fuel filter is easily disassembled for removing water and foreign matter.

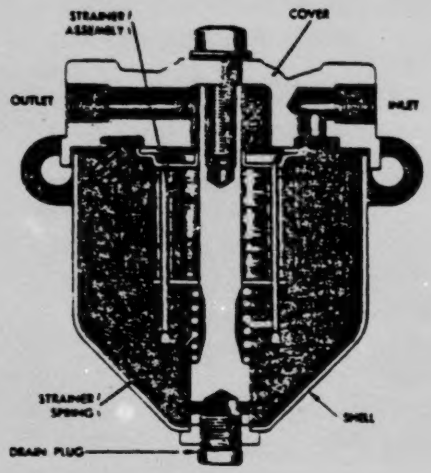


Figure 3A. Disk-type fuel filter.

(3) The tank-type fuel filter and pump assembly (fig 3B) is located inside the fuel tank as a single unit and is accessible from the top of the tank. The pump is a 24-volt, electrically operated, plunger type with a hollow steel plunger in a brass cylinder. The filter element is replaceable, self-contained, and made from helically wound ribbons of phenolic resin impregnated cellulose. Impurities in the fuel are deposited on the edge of the ribbons and can be easily cleaned off without damage to the filter element.

PUMP ELEMENT
GASKET
ORD E5374

Figure 3B. Tank-type fuel pump.

d. Fuel pumps.

(1) Most fuel pumps are actuated by an eccentric on the camshaft through the rocker arm, but some pumps are operated by electricity. Pumps are classified as either positive or nonpositive. Most fuel pumps are nonpositive, which means they cease to pump when the carburetor bowl is full. This is made possible by the type linkage that actuates the diaphragm.

(2) As figure 4 illustrates there is a rocker arm which is held against the eccentric on the camshaft by a spring. When the carburetor bowl is not full and the pump is in operation, the diaphragm in the pump is pulled down as the eccentric moves the rocker arm. This action creates a partial vacuum or low pressure in the fuel line and atmospheric (air) pressure forces gasoline from the fuel tank through the filter and inlet valve and into the pump chamber. The pump chamber is above the diaphragm. As soon as the eccentric permits, the spring under the diaphragm pushes the diaphragm up. This upward movement exerts pressure on the fuel in the chamber and forces it into the carburetor. The fuel cannot return to the tank because the inlet valve is a one-way check valve. Fuel can come in that way but cannot go out. The outlet valve is also a one-way check valve. However, it permits fuel to go out but not to be drawn in. Very often the intake and outlet valves are exactly the same, but the way they are installed causes one to act only as an inlet and the other as an outlet. When the carburetor is full and the pressure above the diaphragm is about 8 pounds, the spring cannot push the diaphragm up. The rocker arm still moves as the eccentric actuates it, but only the lower linkage moves and the diaphragm stays still until the pressure on the fuel is under 8 pounds. The diaphragm is fueltight and airtight and is made of a cloth or fabric that is covered with a petroleum-resistant material.

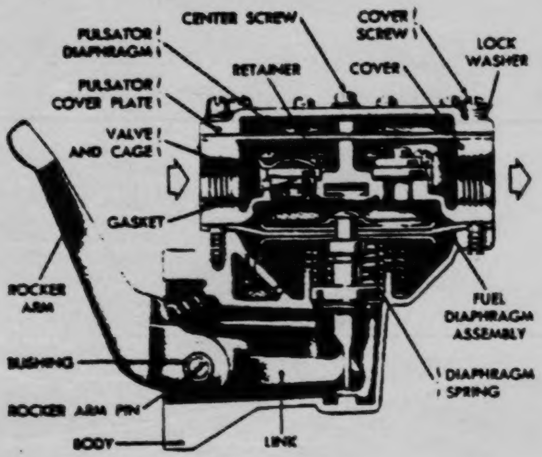
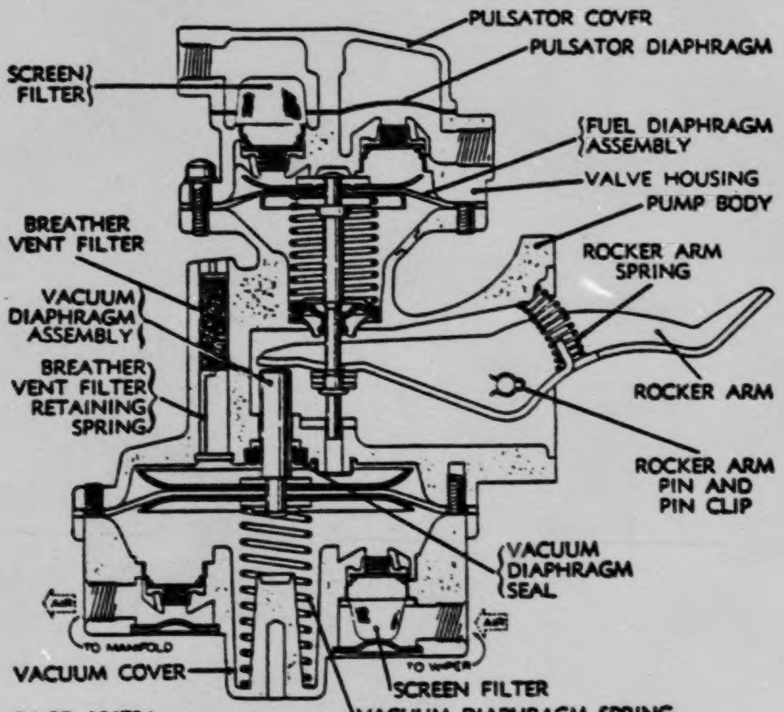


Figure 4. Fuel pump.

(3) Some mechanically operated fuel pumps have vacuum boosters built into them to provide better vacuum for windshield wiper operation. In figure 5 the top half is the vacuum booster and the bottom half a conventional fuel pump. Without this booster, vacuum-type windshield wipers stop or move slowly on acceleration. The booster's only operational connection with the fuel pump is that it is actuated by the same rocker arm. In operation the diaphragm of the booster is pushed down by the rocker arm. This movement expels air from the chamber through the outlet valve to the engine intake manifold. On the return stroke of the rocker arm, the spring moves the diaphragm up to create a partial vacuum or low air pressure in the chamber. This vacuum causes air from the windshield wiper to be admitted through the inlet valve. If the windshield wiper is not used or if there is sufficient vacuum without the booster, atmospheric (air) pressure holds the diaphragm down and the pump is inoperative.


PULSATOR COVER
PULSATOR DIAPHRAGM
SCREEN FILTER
FUEL DIAPHRAGM ASSEMBLY
VALVE HOUSING
PUMP BODY
BREATHER VENT FILTER
ROCKER ARM SPRING
VACUUM DIAPHRAGM ASSEMBLY
BREATHER VENT FILTER RETAINING SPRING
ROCKER ARM
ROCKER ARM PIN AND PIN CLIP
VACUUM DIAPHRAGM SEAL
AIR
AIR
TO MANIFOLD
TO WIPER
VACUUM COVER
SCREEN FILTER
VACUUM DIAPHRAGM SPRING

RA PD 186734

Figure 5. Fuel pump with vacuum booster.

(4) Electric fuel pumps are used on some equipment. These are either solenoid or electric motor operated.

(a) In the solenoid-type, the solenoid operates metal bellows that act somewhat as the diaphragm in the mechanically operated fuel pumps. As the bellows expand, gasoline is drawn in; when they reach their maximum expansion, electrical contacts in the solenoid are tripped open and the bellows release. This allows spring pressure to close the bellows, close the intake valve, and open the outlet valve. The contracting bellows thus force gasoline to the carburetor.

(b) The electric motor type fuel pump is located in the fuel tank and pushes fuel to the carburetor by means of a gear or impeller type pump that is powered by an electric motor.

e. Air cleaners.

(1) Air cleaners remove dust and dirt from the air that passes through the air intake of the carburetor. Dust and dirt are abrasive and cause damage to the pistons and cylinder walls. Some would also get into the crankcase and damage the bearings. An air cleaner usually has a flame arrester to prevent fire in the event of an engine backfire. The air cleaner also silences the "hissing" sound made by air entering the carburetor.

(2) Air cleaners are of two types: wet and dry. The wet-type is an oil-bath cleaner (fig 6). In this cleaner air enters into the body and the compartment containing the metal wool in the filter element. To get to the outlet the air must make a 180° turn above the oil in the oil reservoir. Here, the heavy particles of dust and dirt are dropped into the oil. The air is further cleaned by passing through the curled hair filter in the upper filter element on its way to the outlet. The arrows in the figure show the air movement. This type is more effective in its cleaning action than is the dry-type.

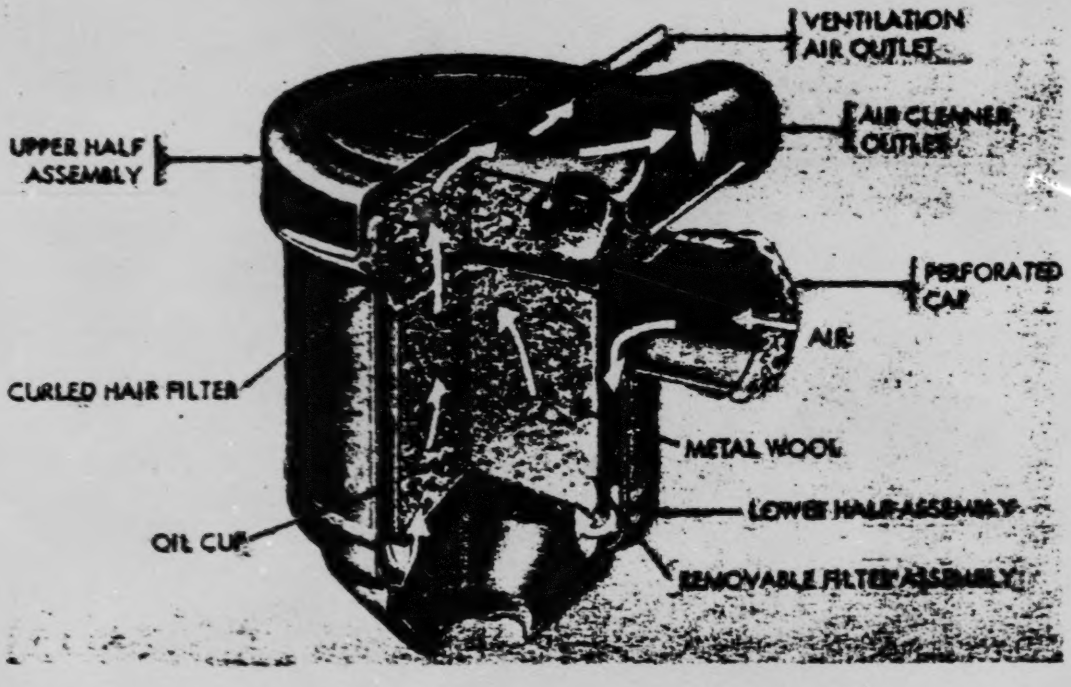


Figure 6. Wet-type air cleaner.

(3) A dry-type air cleaner is pictured in figure 7. This filter has no oil bath. As the arrows indicate, the air is cleaned only by passing through the copper gauze in the cleaner or filter element. In both type cleaners, it is important to keep the gauze clean by washing the dirt out with a solvent. In the oil bath cleaner, the oil in the reservoir must be changed regularly and the sludge in the bottom of the reservoir removed. If the gauze gets choked with dust, the engine may be starved for air and the gasoline consumption will increase. Too much oil in the oil bath cleaner will produce the same result. Dirty filters affect the power of the engine.

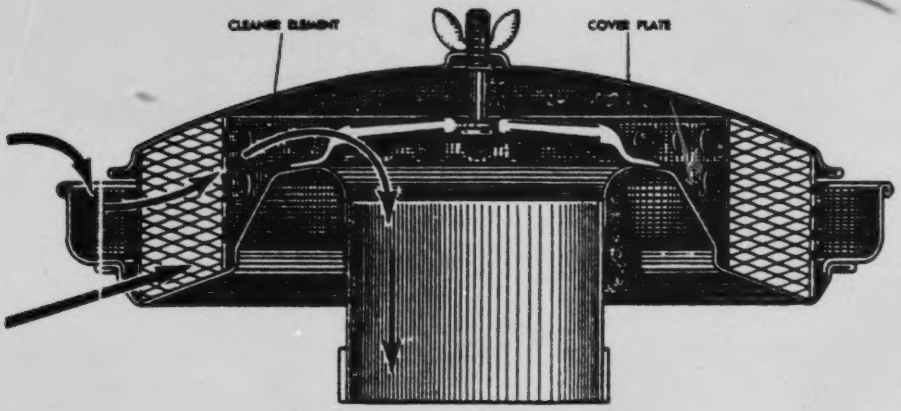


Figure 7. Dry-type air cleaner.

f. Carburetor systems. To this point, we have traced fuel from the tank, through the connections and lines, through the filters, and through the pump. We have also explained how air is cleaned and how it gets into the air horn of the carburetor where it will be "charged" with fuel. The carburetor is between the air cleaner and intake manifold. A fuel line connects it to the fuel pump. The carburetor will be discussed in the next lesson.

g. Intake manifolds.

(1) In the description of the fuel system thus far, the fuel has been brought through the carburetor. From the carburetor it enters the intake manifold. Figure 8 shows the intake and exhaust manifolds for a 6-cylinder engine. The carburetor is mounted on top of the center section of the intake manifold. A thick gasket is between the carburetor and manifold to keep heat from being conducted to the carburetor where it could cause vapor lock.

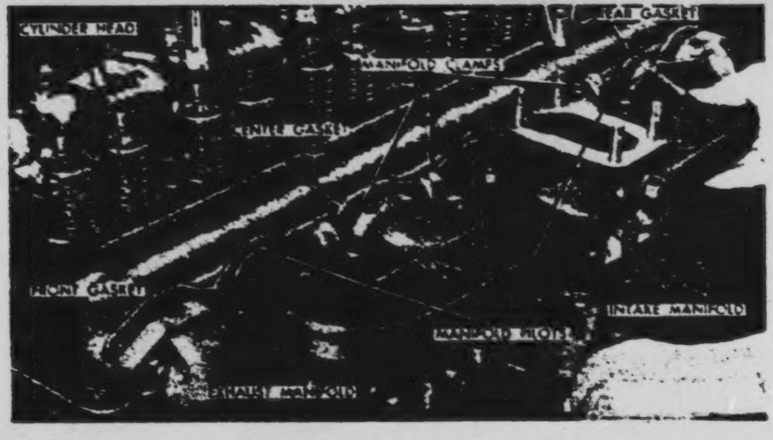

CYLINDER HEAD
REAR GASKET
MANIFOLD CLAMPS
CENTER GASKET
FRONT GASKET
INTAKE MANIFOLD
MANIFOLD PILOTS
EXHAUST MANIFOLD

Figure 8. Intake and exhaust manifolds.

(2) The manifold distributes fuel as evenly as possible to each cylinder and furthers the vaporization of fuel which began in the carburetor. Ideally, fuel and air are completely mixed as a vapor when entering the combustion chamber. The walls of the manifold must be smooth to offer little resistance to the flow of the fuel-air mixture. The intake manifold should be as short and as straight as possible to lessen the chances of the fuel being condensed to a liquid. To assist in the vaporization of fuel, some intake manifolds are constructed so that part of their surfaces can be heated by the exhaust manifold. This is especially helpful until the engine gets warm. A valve placed in the exhaust manifold is actuated by a bimetallic spring that reacts to changes in temperature. When the engine and spring are cold, the spring holds the valve open (fig 9) which causes the hot exhaust gases to pass over part of the intake manifold before being allowed to escape. When the spring gets hot, it closes the valve, or door, and the exhaust passes out the exhaust pipe without circulating around the manifold.

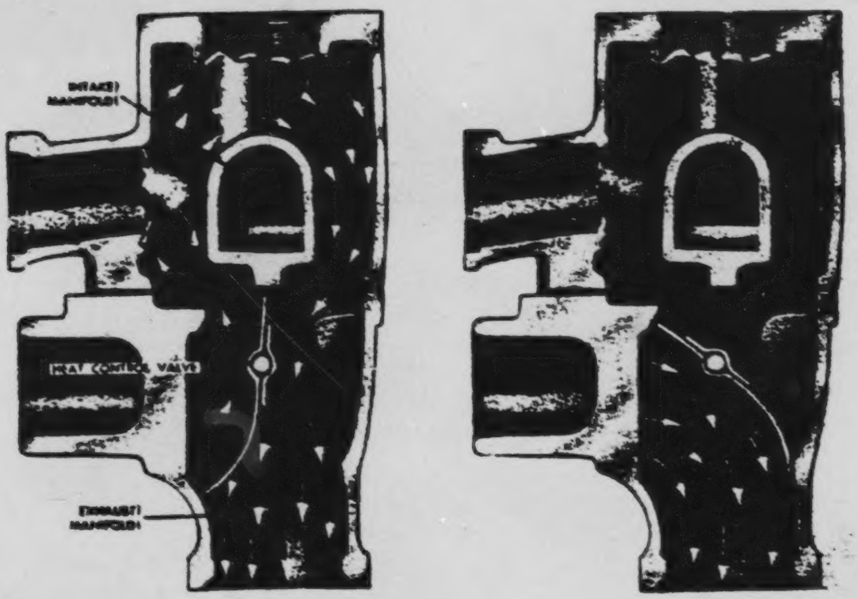

(INTAKE) MANIFOLD
HEAT CONTROL VALVE
(EXHAUST) MANIFOLD

Figure 9. Operation of intake manifold hot spot.

h. Exhaust manifolds. Figures 8 and 9 show both the intake and exhaust manifolds. The exhaust manifold carries the waste gases from the engine. Like the intake manifold, the exhaust manifold should be smooth inside with no abrupt turns to hinder the escape of the gases. If the gases cannot escape freely, back pressure is created in the engine which reduces power and causes overheating. Figure 8 shows there are two end exhaust openings—one for each exhaust valve. The two inner ones are a little wider, and and each picks up the gases from two exhaust valves. Between the cylinder head and both manifolds, there are gaskets to provide an airtight seal. The manifolds are bolted to the cylinder head.

i. Mufflers and tailpipes. Figure 10 shows the complete exhaust system. The exhaust pipe connects the manifold to the muffler. The muffler (fig 11) is designed to muffle engine noise, cool the exhaust gas, and lower exhaust gas pressure. The tailpipe is attached behind the muffler to carry the gases away from the vehicle. Exhaust gases are dangerous if breathed in quantity, so it is important that there are no leaks in the exhaust system.

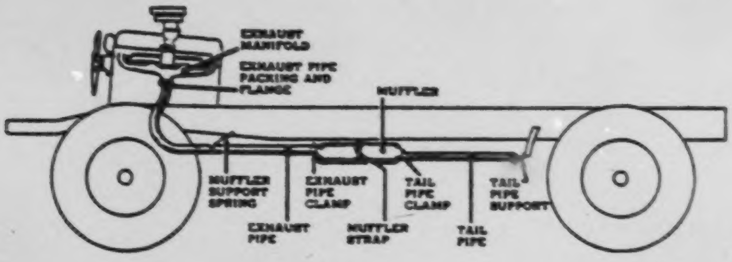

EXHAUST MANIFOLD
EXHAUST PIPE PACKING AND FLANGE
MUFFLER
MUFFLER SUPPORT SPRING
EXHAUST PIPE CLAMP
TAIL PIPE CLAMP
TAIL PIPE SUPPORT
EXHAUST PIPE
MUFFLER STRAP
TAIL PIPE

Figure 10. Exhaust system.

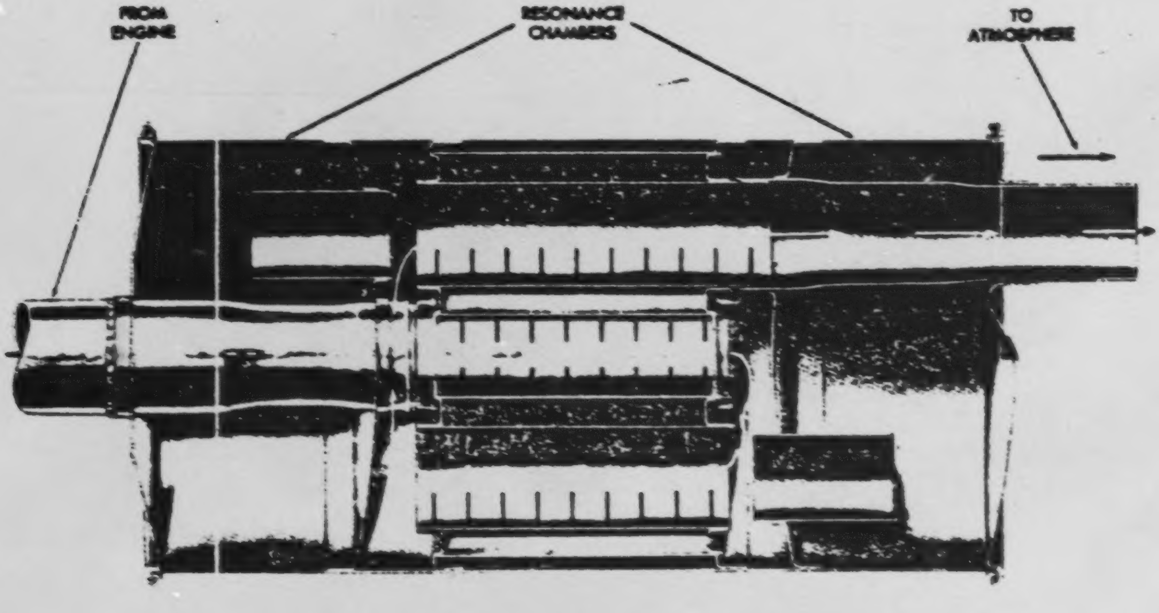

FROM ENGINE
RESONANCE CHAMBERS
TO ATMOSPHERE

Figure 11. Internal construction of a muffler.

j. Governors. Governors are used to set maximum engine speeds. Wear is greater at high speeds. Vehicle speed is, of course, an important factor in safety. Governors work either by centrifugal force, by air velocity, or vacuum. There are several different applications of these principles; however, only one typical example of each kind will be described here.

(1) Figure 12 illustrates the principle of a centrifugal force operated governor, and figure 13 shows a typical velocity operated (vacuum) governor. In the centrifugal governor, the weights fly out as the speed of the shaft, on which they are mounted, increases. As they move out to a predetermined distance, the linkage begins to close the throttle valve and additional speed is prevented. A predetermined speed is made possible by adjusting the spring tension. The drive shaft is driven by the engine camshaft or by an accessory drive from the engine.

(2) When the velocity, or vacuum, governor is used on gasoline engines, it is mounted between the carburetor and intake manifold. This type governor has a throttle valve mounted off center. The mainspring attached to the flywheel on the valve shaft keeps the throttle open at normal or predetermined speeds. As speed increases and the velocity of fuel and air from the carburetor becomes great enough, it tends to overcome the mainspring tension and partially closes the valve. As speed continues to increase, there is a tendency for the valve to be closed further. To prevent closing the throttle altogether, the compensating spring goes into use. As the throttle tends to close, the flywheel shoulder bears against the compensating spring and the proper throttle opening is maintained. This governor, like the centrifugal type, can be adjusted for various maximum speeds.

(3) Some governors are of a combination centrifugal and vacuum, or velocity, type.

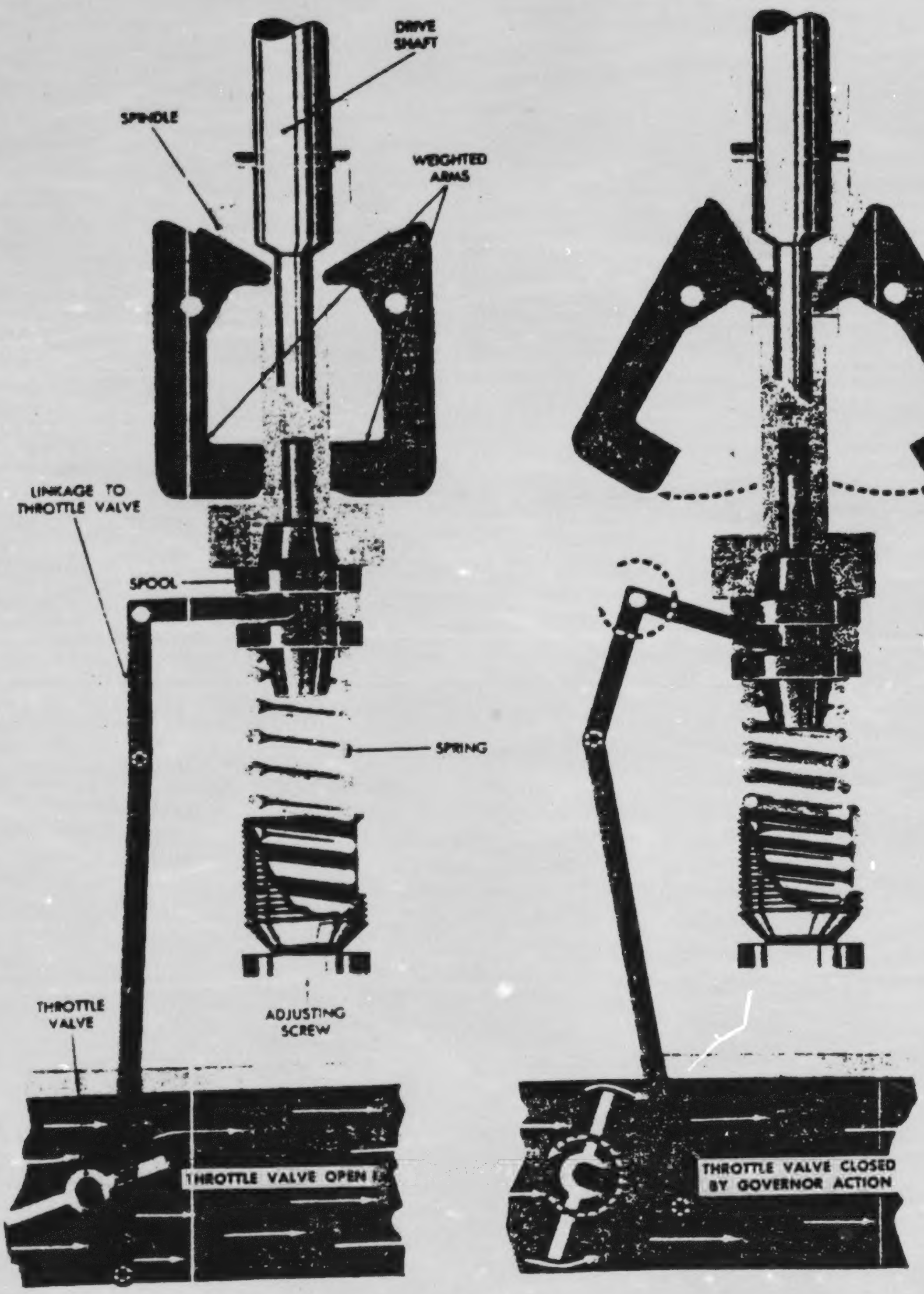
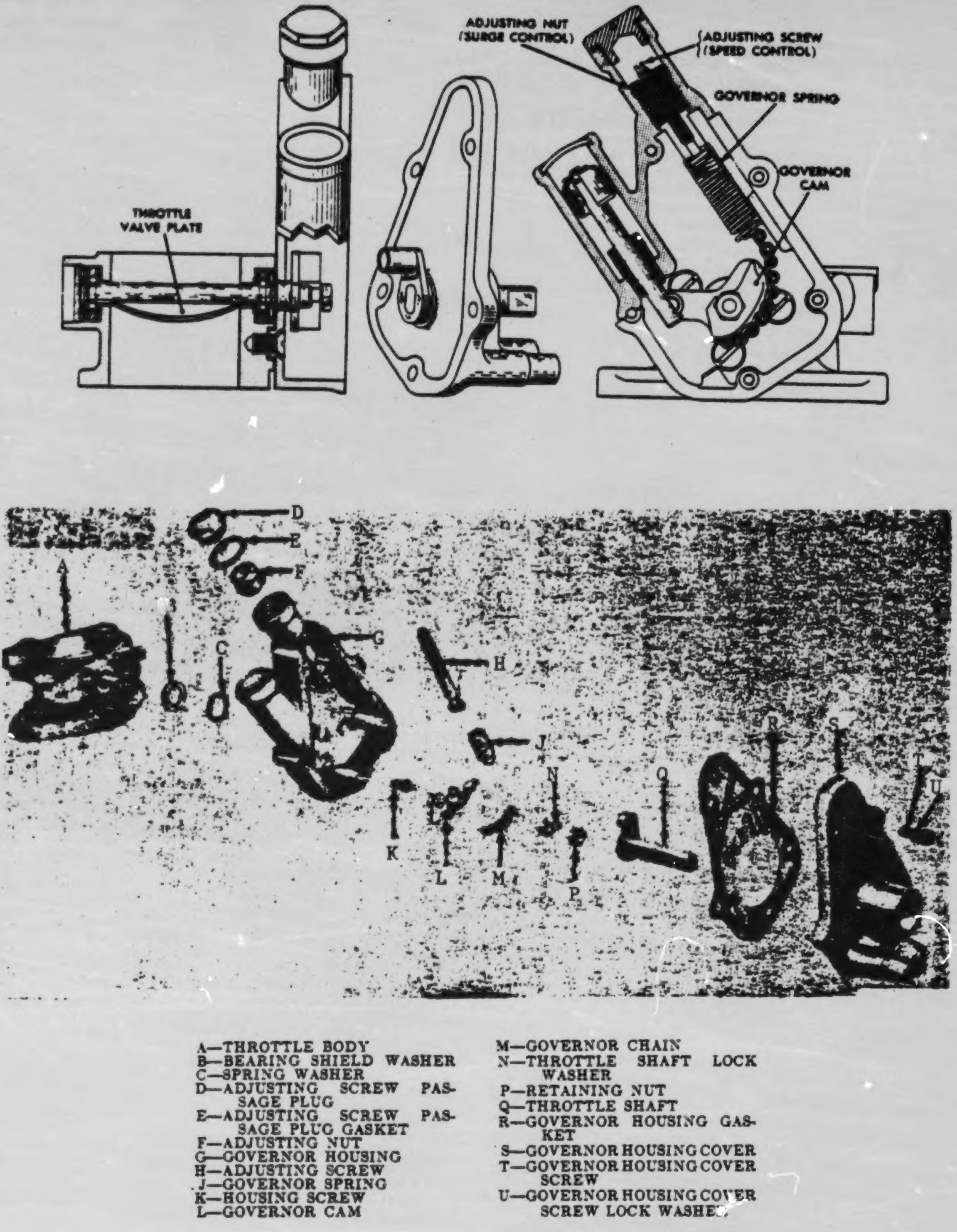

DRIVE SHAFT
SPINDLE
WEIGHTED ARMS
LINKAGE TO THROTTLE VALVE
SPOOL
SPRING
ADJUSTING SCREW
THROTTLE VALVE
THROTTLE VALVE OPEN
THROTTLE VALVE CLOSED BY GOVERNOR ACTION

Figure 12. Centrifugal governor.


ADJUSTING NUT
(SURGE CONTROL)
ADJUSTING SCREW
(SPEED CONTROL)
GOVERNOR SPRING
GOVERNOR CAM
THROTTLE VALVE PLATE
A
B
C
D
E
F
G
H
J
K
L
M
N
P
Q
R
S
T
U

A—THROTTLE BODY
B—BEARING SHIELD WASHER
C—SPRING WASHER
D—ADJUSTING SCREW PASSAGE PLUG
E—ADJUSTING SCREW PASSAGE PLUG GASKET
F—ADJUSTING NUT
G—GOVERNOR HOUSING
H—ADJUSTING SCREW
J—GOVERNOR SPRING
K—HOUSING SCREW
L—GOVERNOR CAM
M—GOVERNOR CHAIN
N—THROTTLE SHAFT LOCK WASHER
P—RETAINING NUT
Q—THROTTLE SHAFT
R—GOVERNOR HOUSING GASKET
S—GOVERNOR HOUSING COVER
T—GOVERNOR HOUSING COVER SCREW
U—GOVERNOR HOUSING COVER SCREW LOCK WASHER

Figure 13. Velocity or vacuum governor.

Note. - Refer to lesson exercise directions, in lesson 1.

21. If the fuel tank of a vehicle is positioned high enough, what component of the fuel system is NOT required?

    a. Intake manifold
    b. Carburetor
    c. Fuel pump

22. Where is a fuel filter normally located?

    a. Between the fuel tank and fuel pump
    b. Between the fuel pump and carburetor
    c. On the carburetor

23. What type of fuel pump ceases to pump when the carburetor bowl is full?

    a. Positive
    b. Gear
    c. Nonpositive

24. What is the purpose of the vacuum booster on some fuel pumps?

    a. To increase the volume of fuel being pumped
    b. To provide for better windshield wiper operation
    c. To provide for smoother acceleration

25. Which is characteristic of the electric motor type fuel pump?

    a. Normally submerged in the fuel tank
    b. Operates on the vacuum principle
    c. Normally mounted close to the carburetor

26. What will cause fuel consumption of an engine to increase?

    a. Fuel lines too large
    b. A clogged vent in the fuel tank cap
    c. Too much oil in the oil bath cleaner

27. What controls the valve to the intake manifold hot spot?

    a. Bimetallic spring that reacts to temperature changes
    b. Electric solenoid controlled by the acceleration linkage
    c. Vacuum control in the intake manifold

3. MAINTENANCE AND REPAIR OF FUEL SYSTEM COMPONENTS.

a. Air cleaner. Air cleaners seldom require repair, but frequent cleaning and servicing are necessary. A wet-type (or oil bath) air cleaner is composed of three sections: body, filtering element, and top cover. A clamp on the bottom of the body holds the air cleaner to the carburetor air horn. By loosening the screw on the clamp, you can remove the air cleaner from the carburetor. Loosening and removing the wingnut on top of the cleaner permits removing the top cover and filtering element. The element should be soaked in cleaning solvent and the dirty oil poured from the bottom of the body. Clean the inside and outside of the body and the top cover with solvent and wipe dry. After the element has soaked in cleaning solvent for 5 minutes, remove it and dry with compressed air. Refill the bottom of the body with a seasonal grade engine oil up to the "Oil Level" line or mark. Do not overfill. Place the element in the body, install the top cover, tighten the wingnut, and the air cleaner is ready for installation.

b. Mechanical fuel pump. A fuel pump can develop many troubles such as a leaky valve, cracked diaphragm, worn rocker arm, broken spring, etc. Although fuel pumps made by various manufacturers differ in design, they all operate on the same basic principles.

(1) When it becomes necessary to rebuild a fuel pump, a standard repair kit should be used. Each kit contains the internal working parts most subject to failure. By the use of a repair kit, an old pump can be made to perform like a new one. The parts contained in a typical kit are shown in figure 14. The "Parts Catalog" section of the applicable technical manual for the type of vehicle on which a pump is installed gives you the correct stock number and nomenclature of the repair kit. The "Overhaul Instructions" part of the same technical manual provides a detailed description, with illustrations, of how fuel pump repairs should be accomplished.

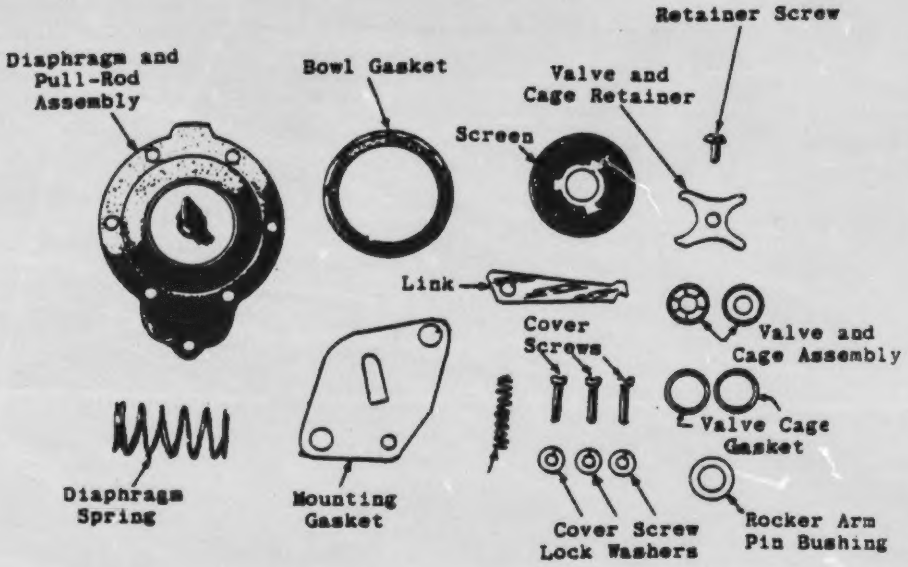

Retainer Screw
Diaphragm and Pull-Rod Assembly
Bowl Gasket
Valve and Cage Retainer
Screen
Link
Cover Screws
Valve and Cage Assembly
Valve Cage Gasket
Diaphragm Spring
Mounting Gasket
Cover Screw Lock Washers
Rocker Arm Pin Bushing

Figure 14. Typical repair kit for fuel pump.

(2) Before removing a fuel pump or disconnecting the fuel lines, clean the outside of the pump housing and the area around the mounting flange and engine block. Select the proper size wrenches (open end or box end, whichever is best suited), disconnect the lines, and remove the pump from the engine block. Cover the opening in the engine block to keep dirt out of the crankcase. Clean the outside of the pump with a good cleaning solvent and dry with compressed air. Do not try to clean the inside of the pump.

(3) After selecting the proper repair kit (by consulting the applicable technical manual) and prior to disassembly, take a fine file and make a crossmark on the flanges where the top cover and pump body come together. By referring to this mark, you can reassemble the top cover and pump body in their original positions. Remove the capscrews which hold the cover to the body; then separate the cover from the body by tapping it lightly around the circumference with a rawhide or wooden mallet. Do not use a hammer. When the top cover is removed, all of the internal working parts are accessible and can be removed easily. Always install all of the parts in the repair kit. This is extra insurance against an early failure, as old parts can be on the verge of failure even when they appear to be in good condition. Clamp the mounting flange of the pump body in a soft jawed vise with the riveted end of the rocker arm up and with the gasket surface of the flange against one jaw of the vise. File off the upset end of the rocker arm pin flush with the face of the washer, so that it can be driven from the pump body, allowing removal of rocker arm and linkage for disassembly. The sediment bowl assembly should be taken off next so that the strainer screen can be removed from the top cover of the pump. The outlet valve and spring should be removed also.

(4) All of the metal parts should be washed in an approved cleaning solvent and all passages blown out with compressed air. If you find the parts difficult to clean, use a special solvent designed for removing carbon deposits. Parts not having replacements included in the repair kit should be inspected thoroughly. The top cover should be replaced if it is warped or cracked. If warped only slightly, it may be flattened by lapping or by using a disk grinder. Replace the bowl gasket seat if it is warped. Replace all valve seat covers of the insert type whenever any part of the raised valve seat is worn off flush with the shoulder of the valve. Sometimes stripped or crossed threads can be corrected with a tap, or they may be drilled out and retapped to a larger size. The pump body should be replaced if the diaphragm flange is warped (unless a slight warping can be refinished by lapping or using a disk grinder) or if the rocker arm stop is broken. If a visual inspection of the rocker arm shows that it is worn or broken, it must be replaced also. Replacement of the cover is necessary whenever the threaded holes in the diaphragm flange are stripped or damaged beyond repair.

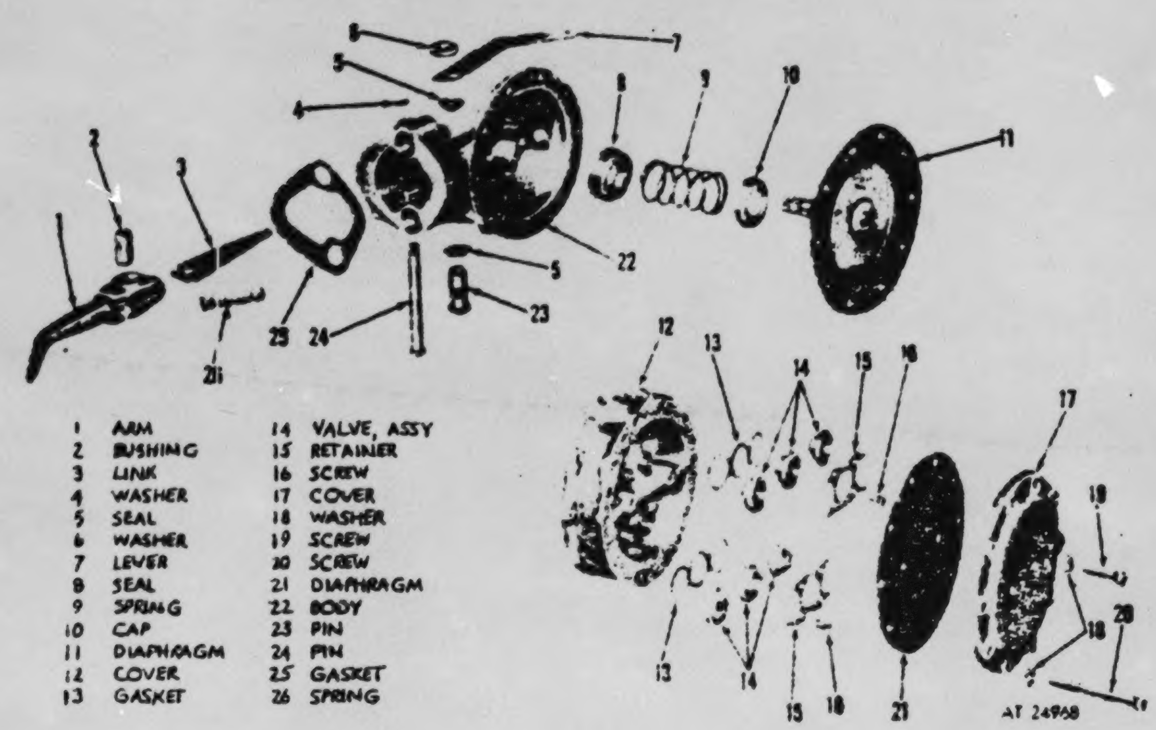
(5) Reassemble the pump only when you are sure that all parts have been thoroughly inspected and, if need be, replaced or repaired. First assemble the pull rod and links. Then place the pull rod in the pump body with the sheared edges of the links up toward the body and threaded end of the pull rod. Insert the rocker arm through the mounting flange so that its hooked end lies between the outer links and over the center link pin. Again, clamp the mounting flange of the pump body in the vise with its gasket surface against one jaw of the vise. Aline the holes in the rocker arm, link, and pump body; then drive in the new rocker arm pin. After installing the rocker arm pin washer on the pin, peen over the end of the pin or install wire pin clips as required.

(6) If there is a priming lever to be installed, lift the pull rod out of the hole and install the lever in the body grooves provided. Open the lever end around the pull rod hole and reinsert the pull rod. Position the diaphragm spring over the inner boss and the rocker arm spring over the outer boss in the bottom cover. Place a spring cap over each spring and put the gasket on the cover. By holding the pump body by the threaded end of the pull rod, you can keep the hand primer in place. Then place the bottom cover and gasket assembly on the body with the spring caps seated against the pull rod and rocker arm. While holding the cover in place, install the cover screws and tighten them securely.

(7) The new diaphragm should be soaked in clean kerosene or diesel fuel before it is installed. Do not use shellac or sealing compound. Place the engine mounting flange of the pump body in the vise with the diaphragm flange upward. Now place the parts of the diaphragm assembly over the threaded end of the pull rod in proper order. Aline the diaphragm holes with the holes in the body flange. Maintain the alinement by temporarily inserting two or three cover screws. Tighten the pull rod nut securely, using another wrench to hold the hex-washer stationary, thus preventing distortion of the diaphragm. Be sure to put the gaskets on the airdome and valve plug. Place a drop of light grade oil on the airdome valve before installing it in the valve chamber over the diaphragm. Just insert the valve spring in the valve plug, tip it into the chamber, and tighten the plug securely. Place the strainer screen and bowl gasket in the top of the cover, position the bowl in place on the cover, swing the bowl assembly into position, and adjust the thumbnut securely with the fingers. Later, check the assembly for leaks at the bowl gasket. If a leak is detected, remove the bowl and check the gasket and gasket seat. Overtightening the thumbscrew with pliers or wrench will probably result in a broken bowl.

(8) The cover must now be installed on the body. Make sure that the file marks on the cover and body are in line. Since the diaphragm spring holds the cover away from the pump body, push on the rocker arm until the diaphragm is flat across the body flange. Install several top cover screws and lockwashers (loosely) until the screwheads just touch the lockwashers. Move the rocker arm into its normal full stroke position and tighten the cover screws securely. Hold the diaphragm in a full stroke (flexed) position, while tightening the cover screws, to properly position the diaphragm between the flanges.

(9) To test the operation of the pump valves, attach an air pressure gage to the outlet side of the pump and operate the priming lever or rocker arm a few strokes while observing the pressure gage. The gage should not show too rapid a pressure drop after the pumping stops. Figure 15 shows the disassembled parts of a typical fuel pump. Some pump units perform a single function, that of delivering fuel under pressure from the fuel supply tank to the carburetor. However, other units incorporate both fuel and vacuum pump sections to accomplish a dual function. This unit supplies fuel from the fuel tank to the carburetor and also pumps air, drawn through the windshield wiper vacuum line, into the intake manifold section. In this manner, more uniform operation of the windshield wiper is provided at all engine speeds and loads. Figure 16 shows the disassembled parts of a fuel pump with a vacuum booster.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AT 24968
1 ARM
2 BUSHING
3 LINK
4 WASHER
5 SEAL
6 WASHER
7 LEVER
8 SEAL
9 SPRING
10 CAP
11 DIAPHRAGM
12 COVER
13 GASKET
14 VALVE, ASSY
15 RETAINER
16 SCREW
17 COVER
18 WASHER
19 SCREW
20 SCREW
21 DIAPHRAGM
22 BODY
23 PIN
24 PIN
25 GASKET
26 SPRING

Figure 15. Exploded view of a fuel pump without vacuum booster.

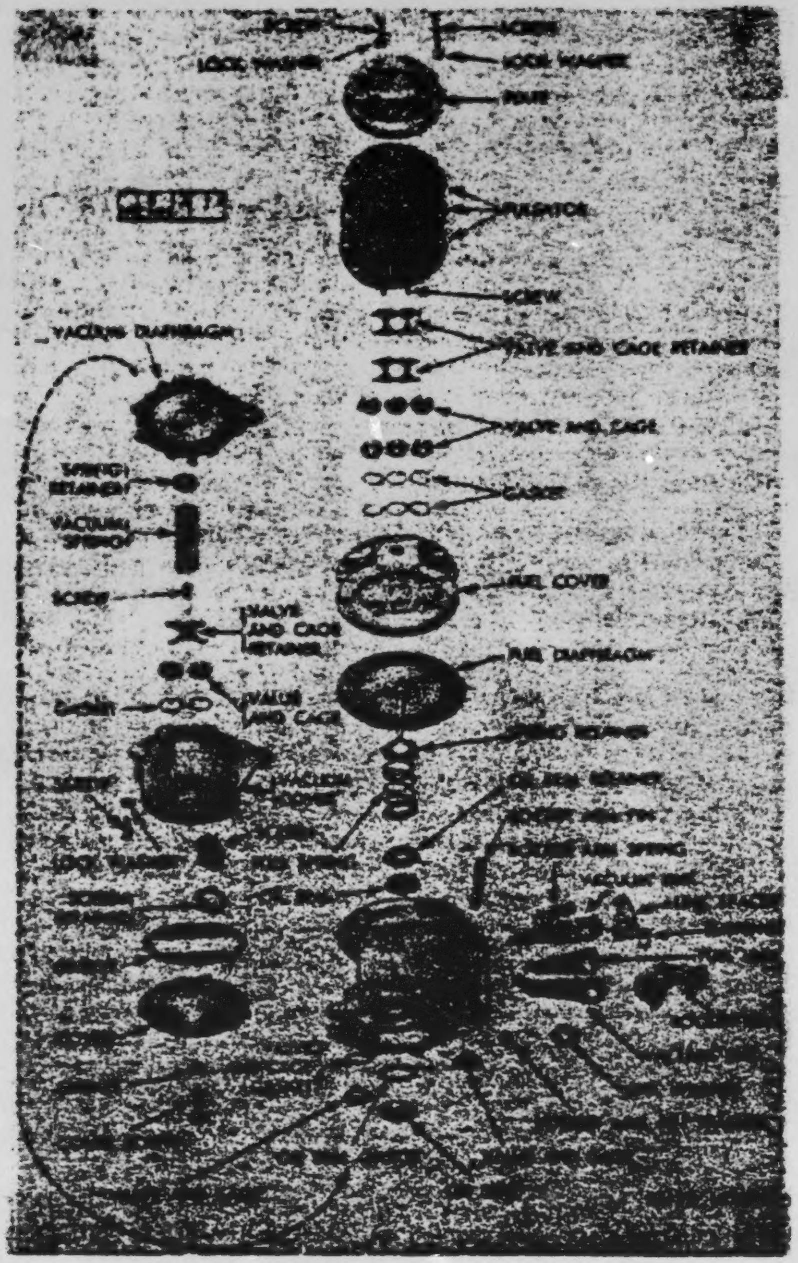

SCREW
LOCK WASHER
SCREW
LOCK WASHER
PLATE
PULSATOR
SCREW
VALVE AND CAGE RETAINER
VACUUM DIAPHRAGM
VALVE AND CAGE
SPRING RETAINER
CAGE
VACUUM SPRING
FUEL COVER
SCREW
VALVE AND CAGE RETAINER
FUEL DIAPHRAGM
GASKET
VALVE AND CAGE
SPRING RETAINER
LOCK WASHER
FUEL SPRING
ROCKER ARM SPRING
VACUUM LINK

Figure 16. Exploded view of a fuel pump with vacuum booster.

(10) When a combination fuel pump and vacuum pump unit is to be overhauled, use a file to mark the edges of the fuel flanges and the heat shield stud position, if a heat shield is used, so that the parts may be reassembled in their original positions. Begin the disassembly by removing the cover heat shield stud. After removing the remaining studs, separate the cover from the pump body by tapping it lightly with a rawhide mallet. Mark the edges of the vacuum cover and pump body flanges. Remove only two of the cover screws from opposite sides of the covers, then substitute two fillister-head screws of the same size and at least 1-1/2 inches long. Turn the two long screws all the way down, and then remove the balance of the regular cover screws. By alternately backing off the long screws a few turns at a time, you permit the force of the heavy vacuum diaphragm spring to be relieved safely. If the flanges stick together after the long screws have been backed off one or more turns, tap the cover lightly with a rawhide mallet to loosen it. After the two long screws have been taken out, the cover assembly, diaphragm spring, and spring retainer can be removed.

(a) File off the riveted end of the pump rocker arm pin until it is flush with the steel washer, drive out the pin with a drift punch and hammer, and move the rocker arm until the links unhook from both diaphragms. Now the rocker arm spring, rocker arm, and link assembly can be removed. Disassemble the rocker arm assembly by removing the linkage and bushing from the rocker arm. Lift the vacuum diaphragm out of the body and remove the lower oil seal retainer by turning it until the slot is lined up with the flat side of the pull rod. This will allow the oil seal assembly to be removed. Remove the fuel diaphragm assembly by pulling it straight out of the body. Be careful not to tilt it excessively or you will damage the oil seal. Disassemble the fuel cover, which was detached previously, by removing the valve and cage retainer screw and bow screws. Disassemble the vacuum cover by removing the valve and cage retainer screw and cover plate screw.

(b) Clean, lay out, and inspect all parts, following the same procedure pattern used with the single unit. When the cleaning, inspection, and exchange of kit parts have been completed, reassemble the pump. Start assembling by placing the link spacer over the fuel link. Place the vacuum links on each side of the fuel link. The hooked ends of the vacuum links should come together so that they surround the fuel link and so that all link hooks point in the same direction. The assembly of links and spacer should now be placed between the lobes of the rocker arm along with the outside spacer washer, so that the rocker arm bushing holds them in place. Now stand the pump body on the bench with the fuel flange down, set the rocker arm spring into position (with one end over the cone cast into the body), and slide the rocker arm and link assembly into the body. The outer end of the rocker arm spring slips over the projection on the link spacer, and the open end of all link hooks must point toward the vacuum flange. You can temporarily retain the assembly in position with a 4- or 5-inch length of 1/8-inch rod.

(c) Soak the new fuel diaphragm in clean kerosene or fuel oil for a short while. Do not use shellac or any other sealing compound between the flanges and the edges of the diaphragm. In the meantime, turn the pump body over with the fuel diaphragm flange upward. Set the diaphragm spring and retainer on the oil seal and push the diaphragm pull rod through these parts. The flat side of the pull rod must be at right angles to the fuel link with its hook at right angles to the link. The diaphragm pull rod can now be hooked to the fuel (short, center) link. Be careful not to tilt the diaphragm pull rod too much or you may damage the oil seals. Remove the temporary pin that was used to hold and aline the rocker arm assembly, drive in the new rocker arm pin, place the washer over the end of the pin, and rivet the pin end by peening it with a ball-peen hammer.

(d) Assemble the parts of the fuel cover, placing the valve and cage gaskets in place before the valves and cages are installed. The inlet valve must have its two-legged spider facing out of the cover. Secure both assemblies with the retainer and screw. Install the strainer screen and other parts in their proper order. If an airdome is used, install it in the threaded hole located in the threaded hole located in the projection of the outlet casting. When installing the cover on the body, make sure that the file marks on the cover and body line up. Move the rocker arm until the diaphragm is flat across the body flange; then install the cover screws and lockwashers (loosely) until the heads begin to touch the lockwashers. Move the rocker arm into its normal full stroke position and tighten all of the cover screws securely. To properly position the diaphragm between the flanges, hold it in a full stroke (flexed) position while tightening the cover screws.

(e) Assemble the vacuum pump cover by placing the two gaskets and two valve and cage assemblies in the cover, so that the three-legged spider of the inlet valve faces out of the cover while the outlet valve faces into the cover, and secure the valves and cages with the retainer and screw. After turning the cover over, set the screen and retainer in the recess located around the valve hole; place the cover gasket, cover, and other parts into proper position; and secure them with the cover screw. Place the vacuum pump cover on the pump body after placing the diaphragm, which has been soaked for a time in clean kerosene or diesel fuel, in proper position between the flanges. Assemble the oil seal on the vacuum diaphragm pull rod in correct sequence and turn the lower retainer 90° in order to lock it in position. Lift the pump body above eye level, so that as you face the vacuum diaphragm flange, the two vacuum links will swing down into view. Then you can hook the vacuum diaphragm pull rod to both links. While holding the vacuum diaphragm in this position, clamp the body in a soft-jawed vise vacuum flange side up. The vacuum diaphragm must be held level with the body flange during the positioning of the vacuum pump cover. You can do this by inserting a piece of steel 3/16 inch by 3/32 by 8 inches, with one end bent to form a right-angle hook which should measure three-eighths of an inch from the bend to the end.

(f) Place the spring and retainer assembly on the riveted end of the diaphragm pull rod. Position the vacuum pump cover over the spring and aline it with the file marks. Insert two screws of correct diameter, but 1-1/2 inches long, into the two opposite holes in the cover flange. Turn these bottom long screws down, alternating a few turns on each. Install the regular screws and washers (loosely) and tighten until the screwheads just engage the lockwashers. Replace the two long screws with the regular screws and washers. The spacer may now be removed from its position between the pump body and rocker arm, thus allowing the heavy vacuum spring to push the diaphragm into a flexed position so that all of the cover screws can be tightened securely.

(g) The vacuum pump side of combination fuel and vacuum pumps is not always bench tested; consequently, when the pump is reinstalled on the engine an operational test of the vacuum pump section should be made by checking the operation of the windshield wiper while the engine is on a power pull. The speed of the wiper blades should remain practically constant during engine acceleration. Should the action be too slow, check the vacuum lines to be sure that they are not either plugged or leaking before jumping to the conclusion that the pump is at fault.

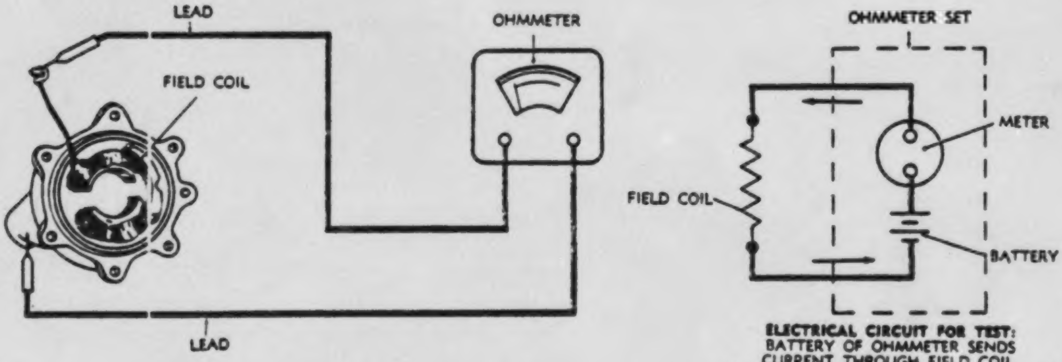
(11) Troubles frequently attributed to the fuel pump may be difficulties involving the fuel supply tank. Failure of a fuel pump to deliver fuel to the carburetor is not always due to a faulty fuel pump, but may be due to faulty fuel lines or an obstruction of some kind in the fuel tank that has settled over the outlet. Temporary relief is provided by disconnecting the fuel line at the fuel pump and blowing compressed air back through the fuel supply line into the fuel tank. However, the only way to permanently remedy such a condition is to remove the fuel tank and clean it thoroughly.

c. Electric fuel pumps.

(1) General. After removal from a vehicle, the fuel pump should be cleaned thoroughly. To clean, use drycleaning solvent or volatile mineral spirits and a soft brush to remove sediment. Blow through all passages with compressed air to make sure they are open. The commutator slots of the armature should be cleaned with a piece of cardboard.

(2) Testing electrical parts.

(a) Field coil test. If resistance of the field coil, when tested as shown in figure 17, is not within limits, use a new or serviceable field housing, bearing, and coil assembly to replace it. Coils for 12-volt pumps should show 25 to 32 ohms of resistance, and for 24-volt pumps 113 to 125 ohms.



ELECTRICAL CIRCUIT FOR TEST:
BATTERY OF OHMMETER SENDS CURRENT THROUGH FIELD COIL. METER MEASURES FIELD COIL RESISTANCE

Figure 17. Test of field coil.

(b) Armature.

1. Test for ground. Test the armature as illustrated in figure 18. Use a 12- or 24-volt test lamp, depending on the pump voltage, and fasten one lead of the test lamp to the armature. Touch each commutator bar, in turn, with the other lead shaft. If the lamp lights when any bar is connected to the test lamp, the armature is grounded and unserviceable. Do not attempt to repair a grounded or shorted armature since the armature is in dynamic balance and cannot be disassembled for repairs.

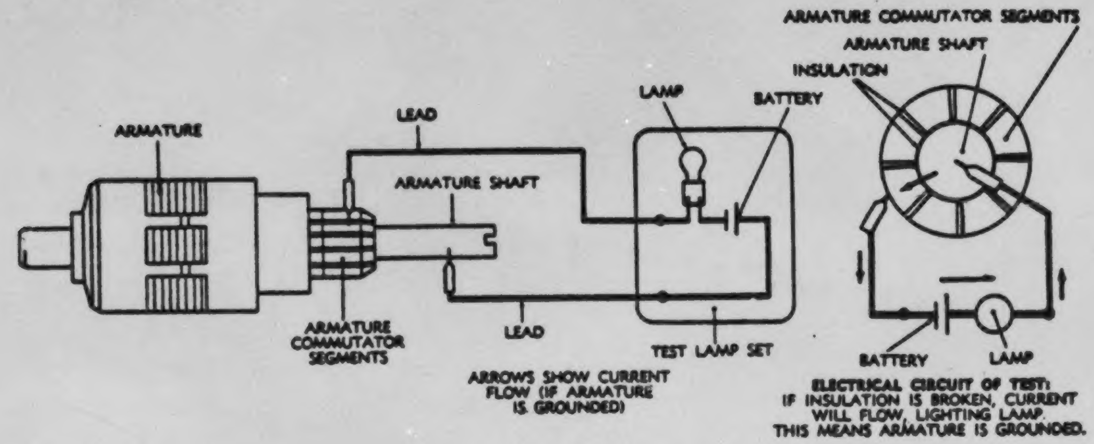

ARMATURE COMMUTATOR SEGMENTS
ARMATURE SHAFT
INSULATION
LAMP
BATTERY
LEAD
ARMATURE
ARMATURE SHAFT
ARMATURE COMMUTATOR SEGMENTS
LEAD
TEST LAMP SET
ARROWS SHOW CURRENT FLOW (IF ARMATURE IS GROUNDED)
BATTERY
LAMP
ELECTRICAL CIRCUIT OF TEST: IF INSULATION IS BROKEN, CURRENT WILL FLOW, LIGHTING LAMP. THIS MEANS ARMATURE IS GROUNDED.

Figure 18. Test of armature for ground.

2. Resistance test A. Measure the resistance of the windings between adjacent commutator bars of armature as illustrated in figure 19. If resistance is not within limits stated below, use a new or serviceable armature assembly. Windings between adjacent commutator bars for 12-volt pumps should test 0.70 to 1.00 ohm for 24-volt pumps the resistance should be 3.0 to 3.85 ohms.

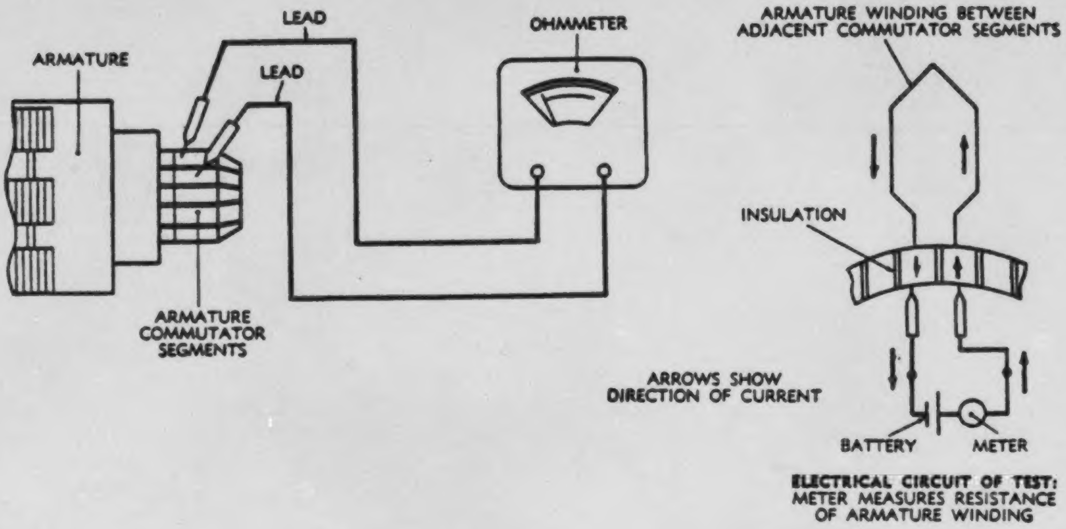

LEAD
ARMATURE
LEAD
OHMMETER
ARMATURE COMMUTATOR SEGMENTS
ARMATURE WINDING BETWEEN ADJACENT COMMUTATOR SEGMENTS
INSULATION
ARROWS SHOW DIRECTION OF CURRENT
BATTERY
METER
ELECTRICAL CIRCUIT OF TEST: METER MEASURES RESISTANCE OF ARMATURE WINDING

Figure 19. Test of armature windings between adjacent commutator bars.

3. Resistance test B. Measure the resistance of the windings between alternate commutator bars as shown in figure 20. If resistance is not within limits stated below, use a new or serviceable armature assembly. Windings between alternate commutator bars for a 12-volt pump should test 1.35 to 1.7 ohms; for 24-volt pumps the resistance should be 5.4 to 7.0 ohms.

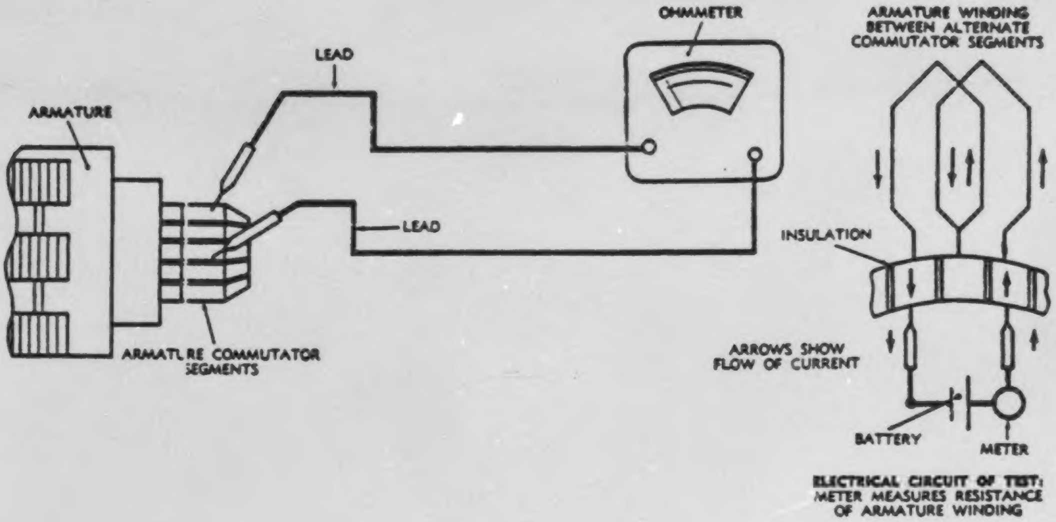

OHMMETER
ARMATURE WINDING BETWEEN ALTERNATE COMMUTATOR SEGMENTS
LEAD
ARMATURE
LEAD
INSULATION
ARMATURE COMMUTATOR SEGMENTS
ARROWS SHOW FLOW OF CURRENT
BATTERY
METER
ELECTRICAL CIRCUIT OF TEST: METER MEASURES RESISTANCE OF ARMATURE WINDING

Figure 20. Test of armature windings between alternate commutator bars.

(c) Cable assembly. Use a 24-volt battery and test lamp and test cable assembly wire for continuity of circuit and for ground. If circuit is grounded or not continuous, use a new or serviceable cable assembly.

(3) Reassembled pump test (fig 21). Attach a pressure gage to the fuel discharge part of pump. Connect a source of power to the pump and submerge the entire pump in a can of drycleaning solvent of volatile mineral spirits. Operate pump by closing the switch. Regulate the rheostat until the voltmeter indicates the rated voltage of the pump. If no undue vibration is observed and if the pressure gage indicates a pressure of 3-3/4 PSI or more, the pump is satisfactory.

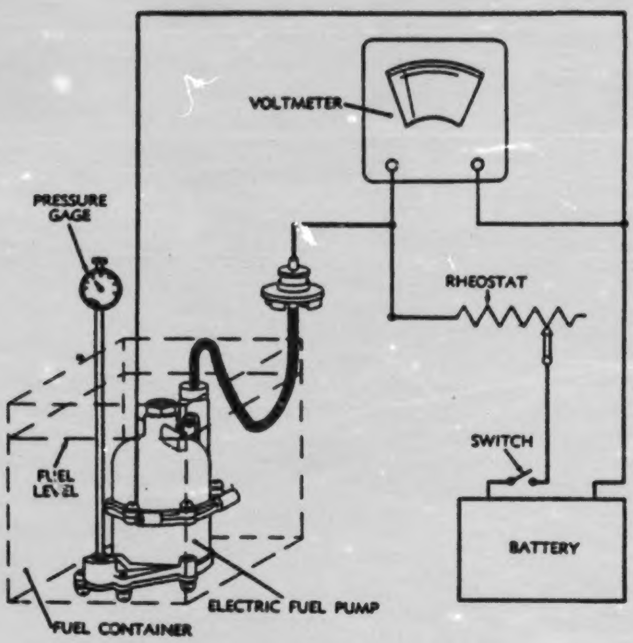

VOLTMETER
PRESSURE GAGE
RHEOSTAT
SWITCH
FUEL LEVEL
BATTERY
ELECTRIC FUEL PUMP
FUEL CONTAINER

Figure 21. Test of electric fuel pump.

Note. - Answer the following questions before continuing to lesson 3.

28. What should be done before disassembling an unserviceable fuel pump?

   a. Make a scribe mark across the top cover and pump body where they come together
   b. Try to clean the inside of the pump by blowing through it with compressed air
   c. Tap the connection joint with a hammer

29. What is the resistance, in ohms, for the field coils of a 12-volt electric fuel pump?

   a. 12 to 20
   b. 25 to 32
   c. 58 to 66

30. What should be used to check the continuity of the cable assembly on an electric fuel pump?

   a. Voltmeter
   b. Ammeter
   c. Battery and test lamp

CORRESPONDENCE COURSE
# of the
US ARMY ORDNANCE
CENTER AND SCHOOL

LESSON ASSIGNMENT

Ordnance Subcourse No 403	Principles of Fuels and Fuel Systems
Lesson 3	Carburetor Circuits
Credit Hours	Three
Lesson Objective	After studying this lesson you will be able to: 1. Describe the purpose and functions of the basic carburetor circuits. 2. Describe the procedures for troubleshooting the carburetor circuits. 3. Describe the procedures for maintenance of carburetors.
Study Assignment	Study the text that follows. It will provide you with information on the purpose and functions of the basic carburetor circuits, and common troubleshooting and maintenance operations on carburetors.
Materials Required	Exercise response list and answer sheet.
Suggestions	Study each illustration as you study the text.

STUDY TEXT

1. GENERAL. The purpose of the carburetor is to supply the correct mixture of fuel and air for any and all conditions of speed and load imposed upon the engine. The engines of present-day vehicles must be completely flexible in the speed range from approximately 500 RPM to more than 3,000 RPM. At any point in this range, the vehicle may be subjected to a comparatively light load or a very heavy load. It must adapt itself immediately to any change of load or speed imposed upon it, within the limits of its maximum power output.

2. PURPOSE AND FUNCTION OF CARBURETOR CIRCUITS.

a. Throttle circuit. The first and most important control that the carburetor requires is a means of varying the amount of fuel-air mixture that enters the intake manifold. When a maximum amount can enter, the engine cylinders will produce maximum power (for the speed at which it is running). When less than the maximum power is required (as when cruising slowly or idling) the engine must be throttled down. This is accomplished by reducing the amount of fuel-air mixture with a throttle valve in the carburetor. The throttle valve is simply a round disk mounted on a shaft so it can be tilted at various angles in the carburetor throttle valve body. When it is parallel to the airflow, it offers almost no restriction and a full volume of fuel-air mixture can pass into the intake manifold. When it is tilted away from this position, it reduces the amount of fuel-air mixture that can pass into the intake manifold. Therefore, engine power is cut down. The throttle valve is connected by linkage to the throttle pedal (accelerator) in the driving compartment. When the pedal is depressed, the throttle valve is opened, which means it is tilted in the throttle valve body so as to offer less restriction and permit more fuel-air mixture to pass through.

b. Float circuit.

(1) The fuel level in the carburetor bowl must be maintained at a constant level during engine operation. If the level is too high, fuel will feed too freely out of the nozzle and the mixture will be too rich; high fuel consumption will result and the engine may suffer from formation of large amounts of carbon in the cylinders. On the other hand, if the fuel level is too low, insufficient fuel will feed from the nozzle and the mixture will be too lean for good engine performance. To maintain the correct level, a float circuit is used. Essentially, this circuit consists of a float pivoted at one side of the bowl and so arranged as to operate a needle valve (fig 1). The fuel pump delivers fuel under pressure to the bowl. When fuel is delivered faster than it is used, the bowl tends to fill up. This causes the float to rise and move the needle valve into its seat. This action shuts off the flow of fuel to the bowl. When the fuel level falls, the float falls also. This allows the needle valve to move out of its seat in order to permit the entrance of more fuel. In actual operation, the float and needle valve maintain a position that permits the fuel coming in to just balance the fuel going out of the bowl.

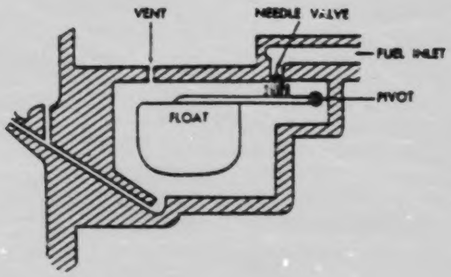


Figure 1. A typical float circuit.

(2) The vent at the top of the bowl (fig 1) may be opened to the atmosphere or it may be vented into the carburetor air horn. In the latter case, a dirty air cleaner will have little effect on mixture richness. However, if the vent is to the atmosphere and if the air cleaner is dirty, the mixture may become excessively rich. The reason for this is that dirt in the air cleaner acts as a restriction and thereby increases the vacuum in the air horn and at the fuel nozzle. This causes a heavier discharge of fuel and greater mixture richness. If the vent is to the air horn, the effect of the dirty air cleaner will be the same on the vent as on the fuel nozzle and there will be no appreciable increase of richness due to the dirty cleaner.

c. Low-speed circuit.

(1) When the throttle is almost closed, there will be very little air passing through the venturi. Therefore, there will be very little vacuum at the venturi and the fuel nozzle will not discharge any fuel. Without some additional circuit to assure fuel delivery with a closed throttle, the engine would stop. The circuit that takes care of fuel delivery during closed or nearly closed throttle is called the idle- and low-speed circuit (fig 2). Actually, in some respects, this is really two circuits, an idle circuit and a low-speed circuit.

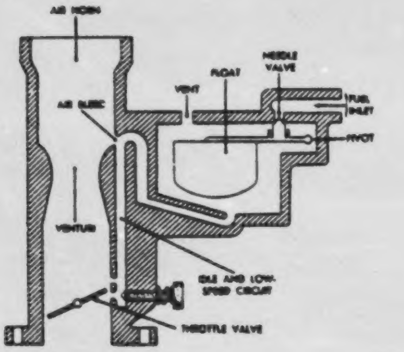


Figure 2. A typical idle- and low-speed circuit.

(2) When the throttle is closed, there is a relatively high vacuum in the intake manifold and below the throttle. The idle circuit has a discharge port, or hole, that is below the throttle valve when it is closed. With a closed throttle, there is a high vacuum in the intake manifold, and at the idle speed discharge hole. Atmospheric pressure in the float bowl will force fuel from the float bowl through the idle circuit and out the discharge hole. An adjustable needle valve is positioned to permit more or less fuel to discharge from the hole. This makes it possible to adjust the idling mixture richness by allowing more or less fuel to discharge during idle.

(3) An air bleed is located between the air horn and the low speed fuel passage to allow air to bleed into the idle circuit when it is operating. This air mixes with the fuel and partly atomizes it before it discharges from the hole into the air horn. Such assistance is needed because air movement through the horn is much slower and there is less tendency for atomization to take place at the hole during idle. The air bleed also helps to produce fuel flow when pressure differences between upper and lower portions of the air horn are low, because the mixture flows easier than liquid fuel alone.

(4) When the throttle is opened a little, the airflow is still too restricted for the venturi to discharge fuel. Yet more air is flowing and, consequently, more fuel must discharge. The idle-circuit discharge hole alone cannot supply this additional fuel. To supply the additional fuel needed for this low-speed operation, an additional hole (low-speed discharge hole or port) is included in the idle circuit. This hole is placed so that it is slightly above the edge of the throttle valve when it is closed, but slightly below the edge of the throttle valve when it is opened a small amount. In this latter position, intake manifold vacuum can act on the low-speed hole and therefore supply additional fuel from the bowl through the circuit. The same circuit is used by both the idle and the low-speed holes. The low-speed hole simply permits more fuel to discharge into the throttle-valve body as the throttle is swung away from the fully closed position.

d. High-speed circuit.

(1) The high-speed circuit consists essentially of the main nozzle, which is centered in the venturi. The carburetor normally contains a multiple venturi; that is, several venturi, one inside another. For example, three venturis are shown in figure 4. When the throttle is opened sufficiently, the air passing through creates a pressure difference which causes a discharge of fuel from the nozzle. Throughout the intermediate and high-speed range, this discharge increases with the volume of air passing through so that a fairly uniform fuel-air mixture ratio is maintained. Assisting in maintaining this fairly constant ratio is an air bleed which is incorporated in the nozzle. With increased air speed through the venturi, increased air bleeding into the main nozzle takes place, preventing overrichness. Note the air bleeds in figures 3 and 4.

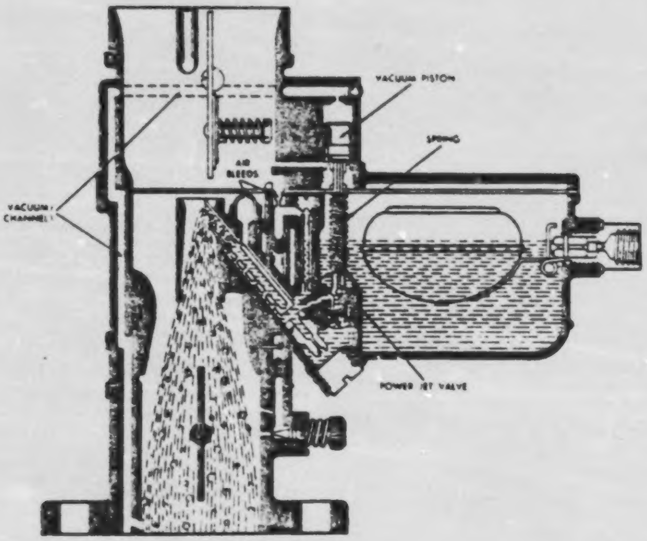

VACUUM PISTON
SPRING
AIR BLEEDS
VACUUM CHANNELS
POWER JET VALVE

Figure 3. Power jet.

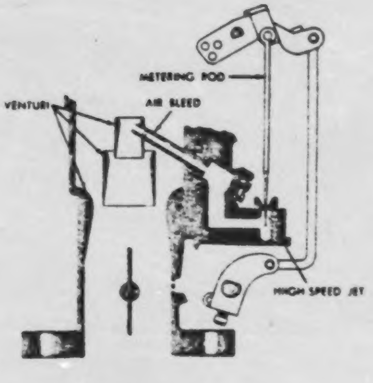

METERING ROD
VENTURI
AIR BLEED
HIGH SPEED JET

Figure 4. Metering rod circuit.

(2) The high-speed and low-speed circuits overlap. For example, as the throttle is moved from the closed to opened position the idle, low-speed and high-speed circuits successively take over the main job of supplying fuel. With a closed throttle, the idle discharge hole alone supplies fuel. As the throttle is opened so its edge moves past the low-speed hole, the low-speed hole begins to discharge fuel to meet the added fuel requirements of the engine as engine speed increases. As the throttle opens still wider, the additional and fast-moving air through the air horn begins to produce fuel discharge from the main nozzle. As the main nozzle takes over, the low-speed discharge hole is closed.

(3) The carburetor is so designed that the fuel-air ratio of the mixture supplied with an open throttle provides economical operation. This ratio is near 15:1 by weight. If the mixture is enriched to around 11:1 or 12:1, the engine will produce greater power, even though it will not run quite as economically. To increase engine power for high-speed or heavy-load operation (as when pulling up a hill), and still maintain reasonable economy, an additional circuit is included in the carburetor which enriches the mixture with a wide-open throttle. Several varieties of full-power circuits are described in (a), (b), and (c) below.

(a) Power jet. In some carburetors, a power jet provides the additional fuel necessary for maximum power at wide-open throttle. The power-jet valve (fig 3), controlled by a vacuum-actuated piston assembly, operates in accordance with the throttle opening. With the throttle closed a high manifold vacuum is present, and the vacuum-controlled piston assembly is moved up by atmospheric pressure in the float chamber to the top of its cylinder against the tension of a spring, closing the valve. When the throttle is opened to a point where additional fuel is required, the manifold vacuum has decreased sufficiently so that the spring on the piston assembly moves the piston down, opening the power jet to feed additional fuel into the high-speed circuit. The jet valve is sometimes referred to as the economizer valve since its operation provides full-power operation where needed and more economical operation at other times.

(b) Metering rod. Instead of using a power jet, some carburetors accomplish the same result by employing a metering rod (fig 4) which varies the size of the high-speed jet openings. Fuel from the float bowl is metered to the high-speed circuit through the calibrated orifice provided by the high-speed jet and the metering rod within it. From this point the fuel is conducted to the nozzle extending into the venturi. As the throttle valve is opened its linkage raises the metering rod in the jet. The rod has several steps, or tapers, machined on the lower end; and, as it is raised in the jet, it makes the effective size of the fuel orifice greater, permitting more fuel to flow through the circuit to meet the load demand imposed on the engine. At the wide-open throttle position the smallest step of the metering rod is in the circular opening of the jet, permitting the maximum amount of fuel to flow through the circuit to meet the requirements of maximum power. The metering rod position must be synchronized with every throttle valve position so the proper ratio of air and gasoline is delivered to the engine for all speeds and driving conditions.

(c) Vacuum step-up. The vacuum step-up (fig 5) operates similarly to the power jet. It consists of a step-up piston which is fastened to a step-up rod. When vacuum develops in the intake manifold, as it does under part-throttle operation, atmospheric pressure holds the step-up piston down against its spring pressure so that the step-up rod is held down in the step-up jet, thus closing off the jet. With wide-open throttle there will be a low vacuum in the intake manifold and the difference in pressure above and below the piston is small. Consequently, the piston is moved up by its spring pressure and the rod is raised out of the jet. Then additional fuel for full-power operation is supplied.

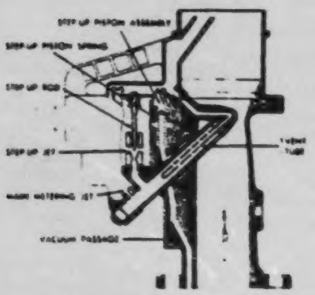


Figure 5. Vacuum step-up circuit.

e. Accelerating pump circuit. The accelerating pump circuit controls a small amount of fuel that is momentarily discharged into the airstream when the throttle is opened quickly. This extra amount of fuel is necessary to insure instantaneous response from the engine on acceleration. When the throttle is suddenly opened, air rushes through both the carburetor and the intake manifold. The air is lighter than the liquid fuel and gets into motion quicker, so it reaches the manifold before the fuel charge supplied by the high-speed system. This results in a momentarily lean mixture. To counteract this condition, additional fuel must be supplied. This is accomplished by the acceleration pump circuit.

(1) The accelerating pump circuit consists of a pump cylinder; a plunger, mechanically actuated by a lever mounted on the throttle shaft, or vacuum-operated by intake manifold vacuum; an intake check valve, located in the bottom of the pump cylinder, to control the passage of fuel from the bowl into the pump cylinder; a discharge check valve; and an accelerating jet to meter the amount of fuel used. A typical arrangement with a mechanically actuated plunger is shown in figure 6.

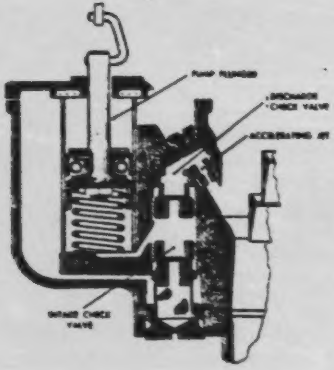


Figure 6. Accelerator circuit.

(2) When the throttle is opened, the pump plunger moves downward in its cylinder. If the plunger is mechanically operated, the downward movement will be brought about by direct linkage with the throttle. If it is vacuum-actuated, a sudden throttle opening will cause the manifold vacuum to drop, allowing the accelerating pump spring to force the pump plunger down in the cylinder. In either case, the subsequent action of the accelerating pump circuit is the same. The downward travel of the plunger forces the fuel past the discharge check valve to the accelerating jet, which meters the rate at which it is

discharged into the airstream. Fuel is supplied to the pump cylinder through the intake check valve at the bottom. The level of fuel in the pump cylinder when the plunger is at the top of its stroke is approximately equal to the level in the fuel bowl. The intake check valve in the bottom of the cylinder permits a supply of fuel to reach the cylinder but closes on the down stroke of the plunger, preventing the fuel in the cylinder from being pushed back into the bowl. The accelerating pump discharge is only needed momentarily when the throttle is opened suddenly. To prevent the accelerating jet from flowing at constant throttle openings, some models have an air-vent check valve placed between the accelerating jet and pump cylinder above the fuel level. At steady part-throttle positions, when the pump plunger is inoperative, no pressure exists on the fuel in the pump cylinder. Under this condition, the air-vent check valve will be open and the air will enter the passage connecting the pump cylinder and accelerating jet, preventing fuel from flowing through the jet. The pressure on the fuel, created by the down stroke of the pump plunger, causes the air-vent check valve to close against its seat to prevent the fuel from being discharged back into the bowl through the air-vent passage. On some carburetors, the area above the plunger is connected to the intake manifold so that the accelerating pump does not work while the engine is not running.

(3) Successful operation of the accelerating pump depends on a delayed action that provides a continual stream of fuel from the pump jet after the throttle has ceased moving. This is to take care of the fuel demands of the engine in the interval that exists between the time the throttle is opened and the time the high-speed nozzle begins to discharge fuel.

(a) Some carburetors achieve this action by means of the dry pump. A pocket of air is maintained in the plunger cup between the plunger and the fuel. When the plunger is pushed down it compresses this air. The compressed air, in turn, forces the fuel from the pump cylinder. At the end of the plunger stroke the compressed air expands, providing the necessary force to continue the fuel discharge. If some of the air below the plunger is absorbed by the gasoline, a small amount of air escapes downward past the plunger, replenishing the supply of air necessary for delayed action in the pump cylinder. A carburetor employing a dry pump does not require an air vent to prevent the accelerating jet from flowing at constant throttle openings. The air remaining in the cylinder is below atmospheric pressure and does not exert enough force to cause fuel to flow. Some models use a pump-connector link spring instead of the pump-connector link. The spring has a double purpose, one of which is to assist in the delayed action of the pump discharge. When the throttle is opened suddenly, the plunger is driven down in the cylinder but the spring is also slightly compressed. As the spring expands to its normal position, it aids in pushing the plunger against the air pocket and assists in the delayed delivery of fuel through the pump jet. The spring will also absorb any strain on the linkage if the pump jet becomes obstructed.

(b) Another type of accelerating pump is called a wet pump and functions without any cushion of air underneath the pump plunger. For its delayed action, this type of pump circuit depends upon the pump spring. Its expansion continues the discharge of fuel for a brief period after the sudden opening of the throttle. This operation is effected by a different linkage arrangement. As the throttle is closed, the pump-operating link raises the plunger in the pump cylinder, compressing the pump spring. When the throttle is opened, the linkage permits the spring to drive the plunger downward.

f. Dual carburetors. Many carburetors, particularly those for engines with more than 6 cylinders, have two barrels. Each barrel is a complete carburetor with its own idle, low-speed, and high-speed circuits, and an accelerator-pump discharge jet. There is a separate throttle valve for each barrel, but both are mounted on a single throttle shaft so that they open and close together. The purpose of the two barrels is to split the responsibility of fuel-air mixture delivery to the various cylinders between two semi-independent carburetors. For instance, in an 8-cylinder, in-line engine, one barrel might take care of cylinders numbers 1, 2, 7, and 8 while the other barrel would take care of cylinders numbers 3, 4, 5, and 6. With such an arrangement there would be two intake manifolds, one feeding one group of cylinders from one barrel of the carburetor and the other feeding the other group from the other barrel.

g. Choke circuit.

(1) When the engine is cold, the gasoline vapors tend to condense into large drops on their way to the cylinders. Because all the gasoline supplied to the cylinders will not vaporize, it becomes necessary to supply a richer mixture to have enough vapor to assure combustion. This is accomplished by the choke circuit, which is a choke valve plate placed in the carburetor throat above the venturi.

(2) When a driver operates the choke, the choke valve tilts in the air horn to reduce the amount of air entering the throat, giving a very rich mixture. Only the volatile parts of the gasoline will vaporize at cold temperatures; therefore, a rich mixture is necessary. It provides enough ignitable vapor to start the engine. However, if the choke valve is in the full-choke position, it is completely closed, shutting off the supply of air. Consequently, there is not enough air entering the throat to ignite the gasoline. The necessary air is admitted in manual chokes by either one of two semiautomatic features.

(a) In one design, the choke valve incorporates a spring-loaded poppet valve (fig 7). The poppet is held in the closed position by a weak spring. As soon as the engine turns over, there is sufficient pressure differential to open the valve, allowing some air to flow.

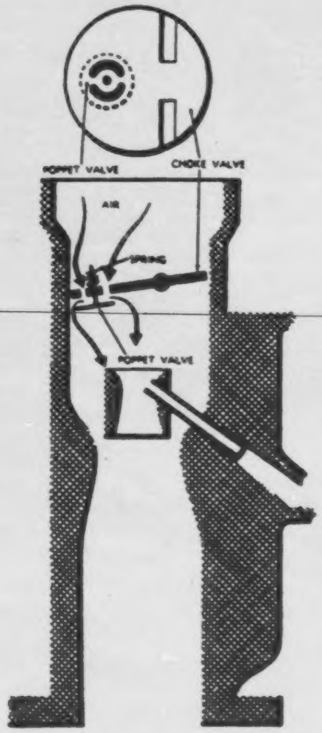


Figure 7. Spring-loaded poppet valve in choke valve.

(b) In the other design, the valve is off-center (fig 8) and operates through a coiled spring on the end of the choke shaft (fig 9). In the full-choke position the spring holds the choke valve in the closed position. As soon as the engine turns over an increased pressure differential overcomes the spring tension and opens the choke valve part way, admitting a small amount of air to avoid overchoking or flooding the engine. As the engine warms up the choke valve is gradually advanced to the wide-open position by the operator to supply the leaner mixture required for a hot engine.

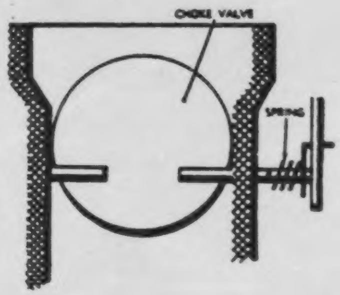


Figure 8. Off-center choke valve.

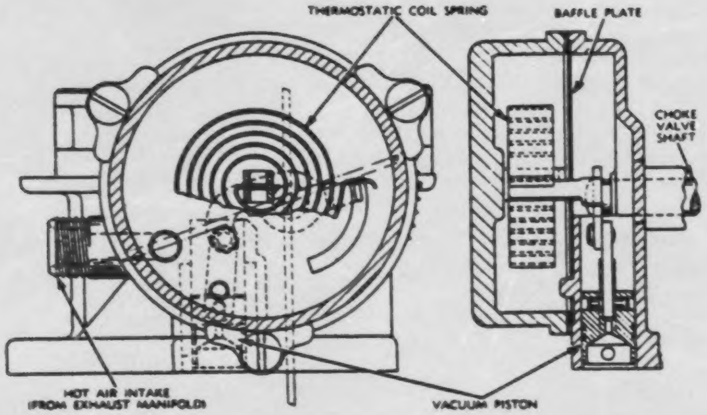


Figure 9. Automatic choke—thermostatic coil spring.

h. Automatic choke.

(1) The automatic choke (fig 9 and 10) replaces the conventional manual choke. It not only controls the fuel-air ratio for quick starting at any temperature, but also provides for the proper amount of choking to enrich the fuel-air mixture for all conditions of engine operation during the warmup period. The automatic choke is built into the carburetor. It consists of a thermostatic (bimetal) spring and a vacuum piston which opposes the action of the spring. The spring is connected to the choke valve in such a manner as to close the valve when the spring is cold. The vacuum piston tends to open the choke valve when the engine manifold vacuum is high. The choke valve is mounted off-center on the choke shaft so that any increase in air velocity through the air horn will tend to open the valve.

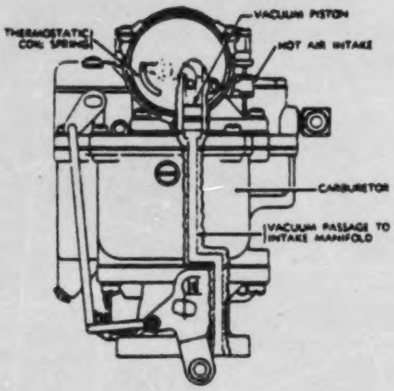


Figure 10. Automatic choke.

(2) The operation of the automatic choke is dependent on three factors: heat, intake manifold vacuum, and the velocity of air passing through the air horn. When the engine is cold the thermostatic spring holds the choke valve closed. When the engine is started the low pressure (high vacuum) below the throttle valve permits atmospheric pressure to move the piston down and partially open the valve against the tension of the thermostatic spring. Under varying load conditions during warmup, the position of the choke valve will be changed by the operation of the vacuum piston working against the thermostatic spring, and by the air velocity in the air horn. Hot air from the exhaust manifold is directed to the thermostatic spring so that the spring loses its tension as the engine is heated. This permits the choke to open gradually and, after it reaches full-open position, it is held open by the action of the intake manifold on the piston. The absence of tension on the heated thermostatic spring and the velocity of the air passing through the air horn will also help to keep the choke open. When the engine is stopped the thermostatic spring cools and closes the choke valve. The choke valve is fully closed at a temperature of approximately 70° F.

3. CARBURETOR TROUBLESHOOTING.

a. General instructions. Efficient operation of a gasoline engine requires that the engine, the fuel system, and the ignition system must operate properly. If any component is not up to specifications, poor engine performance will result. Similar symptoms may result from faulty operation of any of the components. The only way of being sure that a given trouble, such as poor gasoline mileage or hard starting, is being caused by the carburetor is to first check the engine, ignition system, and the fuel system excluding the carburetor. It will also be found that many causes of poor gasoline mileage are the result of bad driving habits or conditions such as excessive use of low speeds in accelerating, sustained high speeds, and stop and start "city" driving.

b. Procedures. It is obvious that the best way to troubleshoot a carburetor is while it is mounted on an operating engine. The repairs and adjustments required can best be determined while operating the engine under all conditions. Paragraph c below lists complaints which may be caused by a defective carburetor. However, it should not be assumed that, when these symptoms are present, the fault is always in the carburetor.

c. Malfunctions and their causes.

(1) Poor gasoline mileage due to rich mixture.

(a) Excessive black smoke emitting from the exhaust pipe and sooty deposits on spark plugs usually result when poor gas mileage is noted. Some of the causes are as follows:

1. Float level set too high.
2. The metering jet is too large or the metering rod is too small.
3. The nozzle gasket was left off when the carburetor was assembled.
4. The metering jet or nozzle is loose.
5. The accelerating pump air vent is clogged.
6. The air bleed hole in the fuel discharge nozzle is stopped up.
7. Holes in the main vent tube are clogged.
8. The fuel pump pressure is too high.
9. The metering rod spring is not connected to the rod.
10. The air cleaner is dirty or clogged.
11. The bowl cover is warped or the cover gasket is damaged.
12. The vacuum passage to the step-up piston is plugged.
13. The choke is stuck in a partially closed position.

(b) White oxide deposit on spark plug insulators and no black smoke from the exhaust pipe is an indication of the mixture being too lean. It can be caused by:

1. The float level set too low.
2. The metering jet too small or the metering rod too large.
3. Two gaskets placed under the high-speed nozzle when the carburetor was installed.
4. The high-speed fuel passage restricted.

(2) Vehicle is hard to start.

(a) During cold weather this is probably due to:

1. The choke not closing properly.
2. The float bowl drain plug leaking.

(b) While the engine is hot, hard starting may be caused by:

1. The automatic choke not opening soon enough.

2. The antipercolator not opening properly.

(3) Lack of power. Normally, the same problems that cause poor gas mileage will also cause an engine to lack power. In addition, depending on the type carburetor used, the following should be checked when performance at wide open throttle is poor:

(a) Piston of the vacuometer not operating.

(b) Piston in the step-up system not operating.

(4) Poor idling performance.

(a) If the engine rolls or gallops during idle, it is usually a result of the fuel-air mixture being too rich. Some of the causes are:

1. The idling jet improperly adjusted.

2. Carbon deposits in the bore of the idling jet.

3. Air bleed passages clogged.

4. Metering hole in the low-speed jet worn too large.

5. Idle adjusting screw damaged as a result of overtightening.

6. The economizer is oversized.

(b) If the engine misfires and vibrates excessively while idling, a lean mixture is indicated. This can be caused by:

1. Idling jet improperly adjusted.

2. Air leaking around the intake manifold gasket.

3. Carburetor flange gasket not tight, allowing air to enter.

4. Leaking around the carburetor main body gasket.

5. Throttle shaft bearings worn.

6. A clogged economizer.

7. The idle orifice tube or metering hole in the low-speed jet clogged.

8. A loose idle port plug.

(5) The engine falters or pops back through the carburetor during acceleration. This type malfunction is normally a result of an insufficient discharge from the accelerating pump circuit. One method of checking it is to remove the air filter and, with the ignition off, suddenly open the throttle all the way while looking into the carburetor throat. If the

pump is operating, the discharge stream of fuel can be seen. This check can be made only if the pump is operated by mechanical linkage. If the system is found to be faulty, check for the following:

(a) Clogged or sticking intake and discharge check valves.

(b) Worn leather on the plunger piston.

(c) A weak pump spring.

(d) Improperly seated ball checks.

(e) A blocked pump passage.

(f) Insufficient travel of the piston.

(g) A clogged vacuum passage.

(h) Air leaking into the vacuum passage.

(6) Carburetor floods or leaks. This malfunction will be noticed during starting, running, and idling. It can be recognized visually, by smell, or by engine performance. The following can cause this condition:

(a) The float level set too high.

(b) A clogged bowl vent.

(c) An improperly seated bowl gasket.

(d) A worn needle or seat in the float jet.

(e) A damaged float jet seat gasket.

(f) Foreign matter lodged between the needle and seat.

(g) A binding float needle.

(h) A cracked bowl.

(7) Engine starts and idles but will not run at high speeds. This can be caused by:

(a) A clogged high-speed jet, nozzle, or passage.

(b) A blocked air cleaner.

(c) Insufficient fuel from the fuel pump.

(d) A clogged fuel filter.

(e) A blocked muffler or tailpipe.

4. CARBURETOR MAINTENANCE. All carburetors are similar as far as castings, locations of passages, jets, and nozzles are concerned. Maintenance personnel, however, should realize the need for using the proper repair kit when overhauling a carburetor. All carburetors have a nameplate attached, which gives the model and number of the carburetor. When ordering replacement parts or repair kits, this model and number should be mentioned to assure that the correct parts or repair kits are furnished.

a. Disassembly. Before disassembling any carburetor, disconnect the control linkage and remove the carburetor from the engine.

(1) To disassemble the bowl cover, disconnect the throttle connector rod at the pump arm and remove the screws attaching the bowl cover; then lift out the bowl cover with all the parts attached. Remove the metering rod (if used), float pin, needle and seat, pump link and plunger, and the pump arm and collar assembly from the bowl cover. The nozzle assembly extends into the primary venturi of the air horn; and the nozzle passage plug, the nozzle retainer plug, and the nozzle assembly must be removed before the air horn can be removed. While detaching and lifting the air horn assembly, be careful not to damage the choke spring. Remove all parts from the body casting. It is best to remove all of the parts that can be removed with one size of screwdriver or wrench and with a minimum of shifting the casting before changing tools or moving the work.

(2) As the various sections of the carburetor are disassembled, they should be laid out by circuits, preferably in a clean, divided tray and on a well-lighted workbench.

b. Inspection, repair, and reassembly.

(1) The idle passages, the idle bypass hole, and the economizer in the body casting must be absolutely clean. Soak the casting for a short time in an approved cleaning solvent and then blow out the passages with compressed air. The carburetor bore must be free from any foreign deposit around the throttle valve. The accumulation of this deposit, to which all carburetors are subjected during prolonged low speed operation, is generally overlooked by an untrained or careless carburetor serviceman. No other factor will contribute as much toward causing rich idle and low-speed operation as does this deposit, which affects throttle operation.

(2) Soak the parts of the air horn and bowl cover in cleaning solvent, and blow them dry with compressed air. Inspect the air horn for an out-of-round condition. Look for dents in the venturis, and check for wear of the choke shaft bearings. Also inspect the bowl cover for warpage. A wire basket usually facilitates the cleaning of the smaller parts. Those parts which are to be replaced by parts furnished in the repair kit, such as the low-speed jet, gaskets, etc, need not be cleaned. Whenever a carburetor is to be completely overhauled, the installation of all the parts furnished in the repair kit package is recommended. The package usually includes the following parts: low-speed jet, nozzle assembly, float pin, needle and seat, pump jet, strainer, pump arm, pump plunger, metering rod and jet, throttle shaft lever, throttle connector rod, pump checks, metering rod disk, and all necessary gaskets, plugs, screws, felt packing, springs, and retainers for complete servicing.

(3) After the carburetor body casting has been cleaned, it should be inspected to insure that the nozzle gasket has been removed from the high-speed passage, that all foreign accumulations and dirt have been removed from all passages and surfaces, and that the idle port is clean and has not been damaged. Check all shoulders and the seats of check valves, low-speed jet, nozzle, and screw plugs so that ports which have been damaged may be replaced. All of the carburetor circuits and their components should be inspected.

(4) Since the fuel enters the bowl through the float valve, the level of the fuel is controlled by the float setting. This float must not be bent out of shape, damaged, or worn, and the float lip must be smooth. Smoothing of the lip may be done with a fine emery cloth, if necessary. The float valve needle and valve seat must be checked for wear. Figure 11 shows enlarged views of a good float valve needle and a badly worn one. Check the needle by sliding the edge of your thumbnail over the seating surface. A groove, caused by contact with the seat, denotes wear of the needle's seating surface and indicates a corresponding amount of wear on the needle valve seat. Needles and seats are obtainable only as matched sets and should be replaced as such.

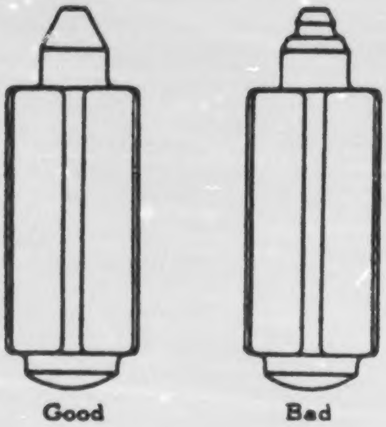


Figure 11. Enlarged view of a float needle valve.

(5) Group together all carburetor parts that control the fuel level. The group should consist of a float pin, needle valve, valve seat, bowl cover, and bowl gasket. These component parts may now be put back together. Install the valve seat and gasket assembly first, and then the needle valve, float, lever assembly, and float pin. Detect wear on the float pin by sliding a fingernail along the surface of the pin in the manner recommended for checking the needle. The float pin hole in the float must not show wear. If you can visually notice any wear, replace the part. Figure 12 shows the correct method used in checking the float level. Make the necessary adjustments by bending only the float lip. Check the applicable technical manual for the correct setting.

(6) Begin the inspection, repair, and assembly of the low-speed circuit with the inspection of the low-speed jet. When a new low-speed jet is installed, the straight end is forced into a tapered seat in the casting to form a seal. When the low-speed jet is removed, it is doubtful whether or not a satisfactory seal can again be effected between the upper tip of the jet and the body casting. Therefore, it is important that the low-speed jet be replaced with a new one whenever it is removed for any reason. There should be one copper gasket under the head of the low-speed jet. Visual inspection of the throttle valve should not show any damage. The valve must be installed with the stamped trademark facing the idle port and the mounting flange.

(7) Group together all of the parts which control the low-speed operation. The group should consist of the low-speed jet and gasket, idle port plug, throttle shaft, valve, and screws. Back out the throttle lever adjusting screw. Position the throttle valve so that the smaller letter "c," inside a circle, or the part number stamped on its face is toward the idle port facing the manifold side of the flange. Be sure to center it before

tightening the screws. Next, install the idle adjustment screw and spring, idle port plug, and a new low-speed jet. Be sure to install a new copper washer in the body of the casting before installing the jet.

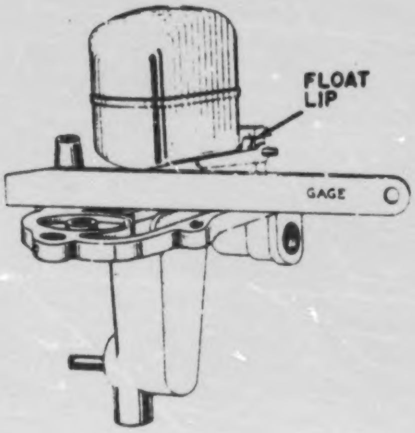


Figure 12. Setting the float level.

(8) The next items to be laid out, inspected, repaired, and reassembled are parts of the pump circuit. Group together all parts of the pump circuit. This group should include the plunger assembly, pump spring, pump connector link, intake and discharge checks, strainer, check passage plug and gasket, pump jet and pump jet plug, pump arm and collar assembly, felt washers, pump cylinder bushing gasket (cork), and necessary retainers for the pump link. The leather gaskets should be soaked in oil to soften them, and they must be clean and in good condition. The plunger itself must be carefully inserted into the cylinder by means of a cylinder loading tool. Install a new pump cylinder gasket. This gasket must be replaced each time the top of the pump cylinder is removed. The check valves and the pump jet must be clean and the parts undamaged. Each of these units must effect a tight seal in the casting. You can test the check valves for free operation by blowing through the assembly. All of the linkage must be free from backlash so that the pump plunger will move as soon as the throttle begins to open. The felt packing on the bowl cover countershaft should be lubricated with engine oil. Other parts of the linkage must not be lubricated but should be kept clean.

(9) Install the pump jet and the pump jet plug, placing a new gasket in the casting before installing the pump jet plug. Next, install the pump discharge check valve and the intake check valve. Insert the strainer in the check valve passage plug and place a new gasket in the casting before installing the plug.

(10) Inspect the component parts of the high-speed system, noting whether the nozzle is clean and undamaged. It is a common error to install the nozzle with two nozzle gaskets or with no nozzle gasket at all. Either of these incorrect installations will result in unsatisfactory performance. The nozzle fits into the small venturi with the flat side up. To properly install a nozzle, hold it stationary while you tighten the nozzle plug. The metering rod disk must be free to move on the metering rod so that it may provide an effective air seat at the metering rod hole in the bowl cover. The metering rod spring must be hooked to the metering rod, which holds it in a steady position in the metering rod jet.

(11) Group all of the parts controlling the high-speed circuit together, including the nozzle assembly, gasket, retainer plug, nozzle passage plug and gasket, metering rod and disk, and the metering rod jet and gasket assembly. Start reassembling the high-speed circuit by installing the bowl cover assembly and cover gasket, the pump connector link, the throttle shaft arm, and the throttle connector rod. Metering rod adjustments are always made during the overhauling of the carburetor or at definite service maintenance periods. The metering rod must be properly gaged after backing out the throttle stop screw located in the throttle lever until the throttle valve is fully closed, or the amount of fuel delivered by the high-speed circuit will be incorrect throughout its entire range. Open the throttle and insert a metering rod gage in the place of the metering rod. Seat the tapered end of the gage in the metering rod jet. With the throttle valve tightly closed and the gage seated in the metering rod jet, there should be less than 0.005-inch clearance between the metering rod pin and the shoulder of the gage. To make an adjustment, bend the throttle connector rod to the necessary angle, using the slotted portion of the tool with the grip handle and bar. When the adjustment has been made, remove the metering rod gage and reinstall the metering rod and disk.

Note. - Answer the questions below.

31. Essentially, the high-speed circuit in a carburetor consists of the

    a. main nozzle.
    b. air horn.
    c. needle valve.

32. What do some carburetors use instead of a power jet?

    a. Air bleed
    b. Choke circuit
    c. Metering rod

33. Which circuit provides fuel delivery during closed throttle operation?

    a. Idle and low-speed
    b. High-speed
    c. Accelerating pump

34. Where does the stepped-end of the metering rod fit?

    a. In high-speed jet
    b. On top of float
    c. Under step-up piston

35. What forces the accelerating pump plunger down in the cylinder if the pump plunger is vacuum-actuated?

    a. Vacuum
    b. Linkage
    c. Spring

36. Which circuit supplies additional fuel when the throttle is suddenly opened?

    a. Accelerating pump
    b. High-speed
    c. Full-power

37. What forces the fuel from the float bowl through the idle circuit and out the discharge hole?

    a. Atmospheric pressure
    b. Accelerator pump
    c. Airflow through venturi

38. What holds the poppet in the choke circuit in the closed position?

    a. Metering rod
    b. Airflow
    c. Weak spring

39. What controls the two throttle valves in a dual carburetor?

    a. Single accelerator pump circuit
    b. Single shaft mounting
    c. Thermostatic springs

40. What opens the off-center choke valve part way when the engine initially starts?

    a. Engine speed
    b. Spring tension
    c. Pressure differential

41. What are the two types of accelerating pumps?

    a. Dry and wet
    b. Plunger and rotary
    c. Positive and variable

42. Where is the intake check valve located in the accelerating pump circuit?

    a. Next to accelerating jet
    b. On bottom of pump cylinder
    c. On top of discharge check valve

43. What will occur if the fuel level in the carburetor bowl is too high?

    a. The mixture will be too lean
    b. The float will fill with fuel
    c. The fuel consumption will be extremely high

44. What provides the heat for the thermostatic spring in an automatic choke?

    a. Exhaust manifold
    b. Cylinder head
    c. Intake manifold

45. There is a relatively high vacuum in the intake manifold when the

    a. engine is operating at high speeds.
    b. throttle is closed.
    c. throttle is open.

46. What helps to produce fuel flow when the pressure differences between the upper and lower portions of the air horn are low?

    a. Venturi
    b. Needle valve
    c. Air bleed

47. Where is the main nozzle located?

    a. In the venturi
    b. Below the throttle valve
    c. In the low-speed circuit

48. What holds the step-up piston down against its spring pressure during part-throttle operation?

    a. Atmospheric pressure
    b. Low-intake manifold vacuum
    c. Main metering rod

49. Which part must have its position synchronized with every throttle valve position?

    a. Needle valve of float circuit
    b. Piston in the accelerating circuit
    c. Metering rod

50. Where is the choke valve plate located?

    a. Below the throttle valve
    b. In the intake manifold
    c. Above the venturi

CORRESPONDENCE COURSE
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LESSON ASSIGNMENT

Ordnance Subcourse No 403	Principles of Fuels and Fuel Systems
Lesson 4	Gasoline Fuel Injection Systems
Credit Hours	Four
Lesson Objective	After studying this lesson you will be able to: 1. Describe the principles of the gasoline engine fuel injection system. 2. Describe the construction of the components of a representative gasoline fuel injection system. 3. Describe the operation of a representative gasoline fuel injection system. 4. Describe the maintenance procedures required of a representative gasoline fuel injection system.
Study Assignment	Study the text that follows. It will provide you with information on the principles of air-fuel injection and the construction, operation, and maintenance of representative gasoline fuel injection system.
Materials Required	Exercise response list and answer sheet.
Suggestions	Study each illustration as you study the text.

STUDY TEXT

1. For an understanding of the principles of air-fuel induction and supercharging systems, study paragraphs 2-1 through 4-1 of ST 9-177.

2. For an understanding of the principles of operation, construction, and maintenance of the Simmonds fuel injection system, study paragraphs 5-1 through 7-5 of ST 9-177.

Note. - Answer the questions below.

51. What is a disadvantage of supercharger equipped engines in comparison to conventional carbureted engines?

    a. Less response is attained for the throttle position
    b. Less torque can be attained at high revolutions per minute
    c. Less economical with respect to fuel consumption

52. In what type fuel injection system is it difficult to vary the fuel input among all cylinders at a uniform rate?

    a. Continuous flow
    b. Timed injection, common rail distribution
    c. Timed injection, independent distribution

53. In timed injection, when is combustion chamber injection more effective than port injection?

    a. During idling speeds
    b. During initial acceleration
    c. During extremely high speeds

54. Which is a characteristic of a fuel injected gasoline engine in comparison to a conventional carburetor engine?

    a. Finer degree of fuel filtration is necessary
    b. Backfiring occurs more frequently
    c. Lag time is greater during acceleration

55. Which model of the Simmonds injection pump is used on the AVSI 1790-6 engine?

    a. SU 15-G
    b. SU 15-D
    c. SU 15-C

56. What regulates the position of the servovalve and skew shaft in the injector pump?

    a. Wobble plate
    b. Sandwich piece
    c. Tuning springs

57. What conditions in the injector pump will NOT affect the servovalve opening?

    a. When the skew shaft is low, with increased manifold pressure
    b. When the skew shaft is high, with decreased servo oil pressure
    c. When the plunger stroke is long, with decreased manifold temperature

58. What component of the injection pump used on supercharged engines reduces the fuel flow correspondingly with reduced airflow at high speeds?

    a. Wobble plate
    b. Metering control valve
    c. Adjustment screw

59. What will cause a fuel injected engine to emit excessive smoke while operating?

    a. Leak in manifold line
    b. Low fuel supply pressure
    c. Restricted fuel lines

60. How will a fuel injected engine react if the metering valve hangs open?

    a. Engine idling will be rough
    b. Engine will not accelerate
    c. Engine will pop under load conditions

61. Why is maximum economy difficult to achieve in an engine?

    a. Incomplete mixing of fuel and air
    b. Excessive atomization and vaporization of fuel
    c. Completely burned fuel

62. What is a limiting factor of a carburetor fuel system for an engine operating at higher speeds?

    a. Long intake manifold aids vaporization of fuel
    b. Large venturi limits fuel supply
    c. Small intake manifold to retain air velocity

63. What statement in relation to gases is correct?

    a. Volume is decreased if temperature is increased
    b. Volume is halved if pressure is doubled
    c. Volume is increased if pressure is applied

64. What increases the power output of a supercharged engine?

    a. Higher compression pressure
    b. Lower burning temperature of gases
    c. Decreased density of fuel-air mixture

65. What device is used to compensate for the increase in cylinder head temperature of a supercharged engine?

    a. Air horn
    b. Manifold heater
    c. Heat exchanger

66. Which is a disadvantage of a supercharged engine?

a. Less engine weight
b. Higher fuel consumption
c. Unimproved torque output

67. What type compressor (pump) is normally used for extremely high speed supercharged engines?

a. Centrifugal
b. Diaphragm
c. Reciprocating

68. Why is the fuel-air mixture requirement of an engine at idling speeds richer than it is for power or the high-speed phase?

a. Exhaust gas dilution is at its minimum
b. Exhaust gas dilution is at its maximum
c. Fuel-air mixture is about 16:1

69. Which component of the injector pump contains self-lubricating qualities?

a. Wobble plate
b. Main shaft
c. Skew shaft

70. What may result when the oil pressure delivered to the Simmonds fuel injector pump is less than 28 PSI?

a. Poor engine idling
b. Fast engine idling
c. Rich air-fuel mixture

CORRESPONDENCE COURSE
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LESSON ASSIGNMENT

Ordnance Subcourse No 403	Principles of Fuels and Fuel Systems
Lesson 5	Multifuel System
Credit Hours	Three
Lesson Objective	After studying this lesson you will be able to: 1. Explain some of the advantages of a multifuel engine. 2. Describe the construction of a multifuel system. 3. Explain the operation of a multifuel system. 4. Describe the principles of a diesel engine. 5. Describe the principles of a multifuel engine. 6. Describe the principles of a gas-turbine engine.
Study Assignment	Study the text that follows. It will provide you with information on the philosophy of multifuel engines, construction and operation of the multifuel system, and the principles of diesel, multifuel, and gas-turbine engines.
Materials Required	Exercise response list and answer sheet.
Suggestions	Study each illustration as you study the text.

STUDY TEXT

1. INTRODUCTION.

a. The key to winning future wars will be mobility. Mobility implies more transport of more people and more weapons than we have ever moved before. The vehicles needed to accomplish greater mobility may some day be powered by turbines, free-piston engines, or nuclear reactors. For the present, however, our vehicles must rely on conventional piston engines.

b. The single factor of fuel consumption is being attacked, not only because of the dire prophecies of ultimate depletion of our petroleum resources, but because reduction in fuel consumption by our forces means overall reduction in expenditures of time, machines, and transportation.

c. Since the piston engine remains our primary powerplant, it is obvious that maximum improvement in economy must be achieved. This can best be done through the use of compression ignition engines.

d. Why are multifuel engines an answer to our problem? No matter how a barrel of crude oil is refined, one of the major end products is gasoline. The requirements of the Armed Forces and internal transport will govern the total quality of middle-distillate fuel that will be available. In addition, the demand by these services for middle distillates and heavier fuels makes it evident that gasoline is the only fuel that will be in relatively long supply. Therefore, it is desirable to have the engines of ground vehicles that operate on middle distillates also be capable of burning gasoline.

e. Compression ignition engines that will run on gasoline can also become engines that will run on fuels of higher cetane. An engine that will operate over a workable fuel spectrum will enable our Armed Forces to fight anywhere in the world on fuels shipped from the continental United States, from its allied producing areas, and on fuels available in the area of action itself.

f. The reason the military has a need for multifuel engines is due to the logistical problem. It is well known that military operations in any area of the world will involve a large amount of automotive equipment. The fuel required to keep the equipment running is enormous, and the transportation of this fuel is a great problem. The burden of transporting fuel required would be reduced if engines would do the following:

(1) Utilize all available fuel in the range from medium octane gasolines through the middle distillates. This would vastly increase the amount of usable fuel available to automotive vehicles.

(2) Operate efficiently on any fuel that is available in its area of operation.

(3) Give better fuel economy than existing powerplants.

g. The multifuel engine is the only powerplant concept that will have the omnivorous but restrained appetite needed to meet these requirements.

2. PHILOSOPHY OF MULTIFUEL ENGINES.

a. A multifuel engine is defined as an engine that meets the following Army requirements:

(1) The engine must operate on most types of petroleum fuel without manual adjustment.

(2) It must start and operate at temperature ranges from -25° F to +115° F without off-engine auxiliary equipment.

(3) It must develop full engine power output on any fuel (proportional only to the specific heat of each fuel).

(4) The engine-cooling system package must weigh no more than 6 pounds per horsepower developed.

b. The first step in developing a multifuel engine was selecting the type of engine that could best be converted. The first engine examined was the one used most extensively by the Army - the gasoline engine. The gasoline engine was readily eliminated for the following reasons:

(1) Gasoline engines operate on high octane, highly volatile fuels, which can only be produced from a small area of the available fuel spectrum.

(2) Fuel economy in gasoline engines is poor, even with the much publicized gasoline injection system. Since shipping of fuel (which exceeded 50 percent of all supplies shipped in World War II and the Korean Conflict) is strictly a logistical problem, gasoline engines are not economically practicable.

c. Other engines, such as the gas turbine and free piston engines, are truly multifuel engines. Gas turbines show much promise. Development programs are being conducted in the 600-horsepower range and also the 300 horsepower area. These turbines are expected to approach diesel engine fuel economy at part and full load.

d. The diesel engine was selected because it is an internal combustion engine like those previously discussed. It requires air, fuel, and ignition.

3. DIESEL ENGINES.

a. Definition. A diesel engine is an internal combustion engine in which ignition is derived from the heat of compression. The diesel engine requires no aid for ignition; the fuel being ignited solely by contact with the air heated during the compression stroke.

b. History. The diesel engine bears the name of Dr. Rudolph Diesel, a German engineer. He is credited with constructing, in 1897, the first successful diesel engine using liquid fuel. His objective was an engine with greater fuel economy than the steam engine, which used only a small percentage of the energy contained in the coal burned under its boilers. Dr. Diesel originally planned to use pulverized coal as fuel, but his first experimental engine in 1893 was a failure. After a second engine also failed, he changed his plan and used liquid fuel. The engine then proved successful.

c. Applications. The diesel engine today can be used for almost as many purposes as can the gasoline engine. The early diesel engines were large and heavy compared to gasoline engines and were used chiefly for heavy duty stationary applications. Constant improvement through the years has brought them to the point that they can be used successfully in trucks and buses. They are still relatively heavy and expensive (initial cost) when compared to their gasoline counterparts, but their high thermal efficiency makes them quite suitable for any heavy duty application, where, over a long period of time, they will pay for themselves many times over in fuel savings. One of the most recent applications has been in the field of armored combat vehicles, with the introduction of the M60 tank, which is powered by an air-cooled diesel engine.

d. Diesel engine classifications. The major classification of American diesel engines is established by the speed at which the engine normally operates. The Society of American Engineers has set up a standard classification that is followed by all American manufacturers. This classification is as follows:

(1) Low speed - below 500 RPM (revolutions per minute).

(2) Medium speed - 500 to 1,000 RPM.

(3) High speed - over 1,000 RPM.

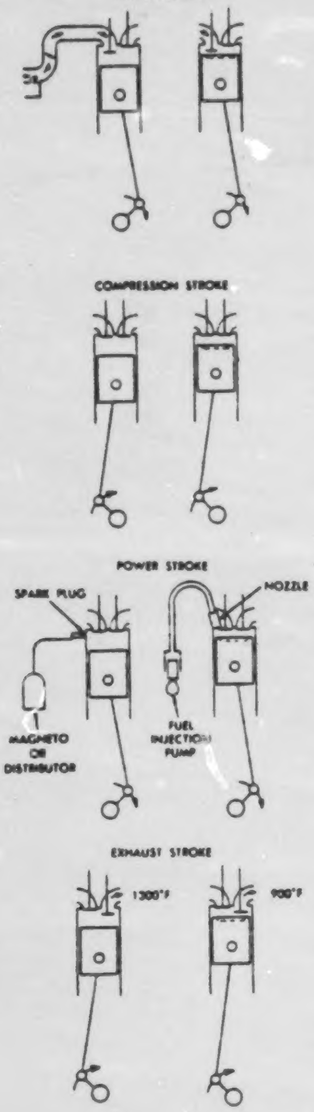
e. General mechanical construction. The diesel engine is mechanically similar to the gasoline engine but is somewhat heavier in construction due to higher cylinder pressures. Both engine types utilize air, fuel, compression, and ignition, Intake, compression, power, and exhaust occur in the same sequence; arrangements of pistons, connecting rods, and crankshafts are similar. Both are internal combustion engines; that is, they extract energy from a fuel-air mixture by burning the mixture inside the engine.

f. Principles of the 4-stroke diesel cycle.

(1) Fuel intake and ignition of fuel-air mixture. In principles of operation, the main differences between 4-stroke cycle gasoline and diesel engines (fig 1)are the methods of introducing the fuel into the cylinder and of igniting the fuel-air mixture. Fuel and air are mixed together before they enter the cylinder of a gasoline engine. The mixture is compressed by the upstroke of the piston and is ignited within the cylinder by a spark plug. Air alone enters the cylinder of a diesel engine on the intake stroke. The air is compressed by the upstroke of the piston and the diesel fuel is injected into the combustion chamber near the top of the upstroke (compression stroke). The air becomes greatly heated during compression and the diesel fuel ignites and burns as it is injected into the heated air. No spark plug is used in the diesel engine; ignition is by contact of the fuel with the heated air, although "glow plugs" are used in some models of diesel engines to assist in starting. Pressure developed by the compression stroke is much greater in the diesel engine, in which pressures as high as 500 pounds per square inch (PSI) are common. For each pound of pressure exerted on the air, there will be a temperature increase of about 2° F. At the top of the compression stroke (when pressure is highest), the temperature in the chamber will be about 1,000° F. This heat ignites the fuel almost as soon as it is injected into the cylinder, and the piston, actuated by the expansion of the burning gases, then moves down on the power stroke. In a gasoline engine, the heat from compression is not enough to ignite the fuel-air mixture so a spark plug is necessary.

(2) Control of speed and power. The speed and the power output of diesel engines are controlled by the quantity of fuel injected into the cylinder. This is opposed to the common gasoline engine that controls speed and power output by limiting the amount of air admitted to the carburetor. The difference is that the diesel engine controls the quantity of fuel, whereas the gasoline engine regulates the quantity of air. In the diesel engine, a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder on each intake stroke. Because the quantity of air is constant and the amount of fuel injected is below the maximum established by the manufacturer in designing the engine, there is always enough air in the cylinder for complete combustion. A device in the carburetor of the gasoline engine controls the amount of air admitted. The amount of air and its velocity, in turn, control the quantity of fuel that is picked up and mixed with air to be admitted to the cylinder. The amount of mixture available for combustion determines power output and speed. The controlling factor in the speed and power output of a gasoline engine is the amount and velocity of air passing through the carburetor.

(3) Combustion process. In the diesel engine, there is continuous combustion during the entire length of the power stroke, and pressure resulting from combustion remains approximately constant throughout the stroke. In the gasoline engine, however, combustion is completed while the piston is at the upper part of its travel. This means that the volume of the mixture stays about the same during most of the combustion process. When the piston does move down and the volume increases, there is little additional combustion to maintain pressure. Because of these facts, the cycle of the gasoline engine is often referred to as having constant volume combustion while the diesel cycle is said to have constant pressure combustion.

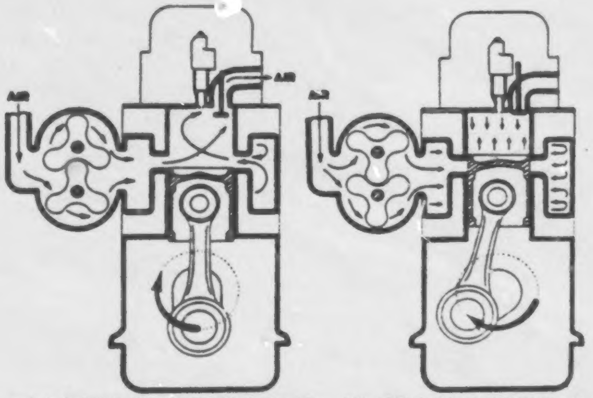


GASOLINE		DIESEL
ON DOWNWARD STROKE OF PISTON, INTAKE VALVE OPENS AND ATMOSPHERIC PRESSURE FORCES AIR THROUGH CARBURETOR WHERE IT PICKS UP A METERED COMBUSTIBLE CHARGE OF FUEL. THE MIXTURE GOES PAST THE THROTTLE VALVE INTO CYLINDER SPACE VACATED BY THE PISTON	INTAKE STROKE	ON DOWNWARD STROKE OF PISTON, INTAKE VALVE OPENS AND ATMOSPHERIC PRESSURE FORCES PURE AIR INTO THE CYLINDER SPACE VACATED BY THE PISTON. THERE BEING NO CARBURETOR OR THROTTLE VALVE, CYLINDER FILLS WITH SAME QUANTITY OF AIR, REGARDLESS OF LOAD ON THE ENGINE
ON UPSTROKE OF PISTON, VALVES ARE CLOSED AND MIXTURE IS COMPRESSED, USUALLY FROM 70 TO 125 PSI, DEPENDING ON COMPRESSION RATIO OF ENGINE.	COMPRESSION STROKE	ON UPSTROKE OF PISTON, VALVES ARE CLOSED AND AIR IS COMPRESSED TO APPROXIMATELY 500 PSI
COMPRESSED FUEL-AIR MIXTURE IS IGNITED BY ELECTRIC SPARK. HEAT OF COMBUSTION CAUSES FORCEFUL EXPANSION OF CYLINDER GASES AGAINST PISTON, RESULTING IN POWER STROKE.	POWER STROKE	HIGH COMPRESSION PRODUCES HIGH TEMPERATURE FOR SPONTANEOUS IGNITION OF FUEL INJECTED NEAR END OF COMPRESSION STROKE. HEAT OF COMBUSTION EXPANDS CYLINDER GASES AGAINST PISTON, RESULTING IN POWER STROKE.
UPSTROKE OF PISTON WITH EXHAUST VALVE OPEN FORCES BURNED GASES OUT, MAKING READY FOR ANOTHER INTAKE STROKE.	EXHAUST STROKE	UPSTROKE OF PISTON WITH EXHAUST VALVE OPEN FORCES BURNED GASES OUT, MAKING READY FOR ANOTHER INTAKE STROKE.

Figure 1. Comparison of sequence of events in diesel and gasoline engines.

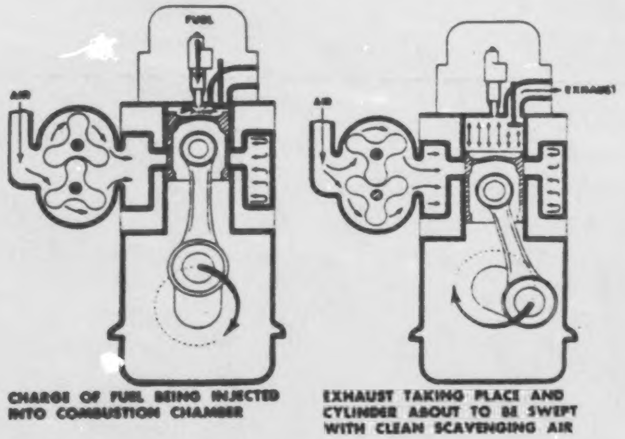
g. Principles of the 2-stroke diesel cycle.

(1) Operating principles. The 2-stroke diesel cycle differs from the 4-stroke cycle in that one power stroke occurs for each revolution of the crankshaft, as shown in figure 2. Intake, compression, injection, power, and exhaust still take place, but they are completed in just two strokes on the piston (one revolution of the crankshaft). Also, in many engines there are no intake or exhaust valves. Instead there are intake and exhaust ports which are cut into the cylinder wall. These ports are covered and uncovered by the piston at the proper times to provide for the intake of air and the exhausting of the products of combustion. Some engines have intake ports in the cylinder wall, but have exhaust valves in the top of the combustion chamber. One of the main advantages of using ports rather than valves is that there are fewer moving parts in the engine, and thus fewer maintenance problems. Since the time for intake and exhaust is limited in the 2-stroke diesel cycle engine, air is usually supplied under pressure by a blower. Because the products of combustion are usually being exhausted when the intake ports are uncovered, the incoming air helps push these exhaust gases out of the cylinder. This effect is called scavenging, and the airflow during scavenging in a typical 2-stroke cycle diesel engine can be seen in the upper left of figure 2. Another advantage of scavenging is that, since the blower supplies air to the cylinders under pressure, more air can enter the cylinders than would be able to enter if the pressure were atmospheric. Thus, there is more oxygen available for the combustion of the diesel fuel.



AIR ENTERING COMBUSTION CHAMBER THROUGH CYLINDER LINER PORTS

AIR BEING COMPRESSED WITH THE EXHAUST VALVE CLOSED



CHARGE OF FUEL BEING INJECTED INTO COMBUSTION CHAMBER

EXHAUST TAKING PLACE AND CYLINDER ABOUT TO BE SWEPT WITH CLEAN SCAVENGING AIR

Figure 2. Schematic diagrams depicting the 2-stroke diesel engine.

(2) Applications. The 2-stroke cycle is used for both spark ignition and compression ignition engines. However, its use for the spark ignition engine is normally restricted to those of low power output, such as power lawnmowers, portable air compressors, and portable marine engines. The 2-stroke gasoline engine is rather inefficient because some of the incoming charge, which includes fuel, may be lost to the atmosphere through the exhaust ports in order to obtain high power output per unit displacement. The diesel engine made the 2-stroke cycle practical. It will be recalled that the intake charge of the diesel engine consists only of air. Therefore, no potential chemical energy is lost should some of the charge be expelled to the atmosphere through the exhaust ports. In fact, such a condition will assure more complete scavenging of exhaust gases and, hence, a maximum amount of air is available in the combustion chamber to burn the incoming fuel.

h. Comparison of the 2-stroke and 4-stroke diesel cycles. Since the 2-stroke cycle has one power stroke per crankshaft revolution while the 4-stroke cycle produces one power stroke per two revolutions, it should first appear as though the 2-stroke cycle engine would be capable of delivering twice as much power as a 4-stroke cycle engine of the same piston displacement. However, there are many practical considerations which limit the power of a 2-stroke cycle engine to less than twice as much as the output of a comparable 4-stroke cycle engine. Due to the factors discussed in the next two paragraphs, it will be seen that both the 4-stroke cycle and the 2-stroke cycle diesel engines have their advantages and disadvantages.

(1) Characteristics affecting power output. To allow for reasonable scavenging of the exhaust gases from the cylinder of a 2-stroke engine, the exhaust valves or ports must open earlier than in a 4-stroke cycle engine. Thus, the effective power stroke in a 2-stroke cycle engine is shorter than in a 4-stroke cycle engine with the same total piston travel. In addition, the incoming air must help scavenge the exhaust gases in a 2-stroke cycle engine and, thus, less air is actually available for combustion purposes than in a 4-stroke cycle engine with the same piston displacement. This is compensated for, to a certain extent, by the fact that most 2-stroke cycle diesel engines use a blower that forces air into the cylinder under pressure. The power required to drive the blower on a 2-stroke cycle engine must be furnished by the engine itself, and this, of course, decreases the power output.

(2) Heat dissipation characteristics. An important factor to consider when evaluating the relative merits of the 2-stroke and 4-stroke diesel cycles is heat dissipation characteristics. In a 4-stroke cycle engine, there is more opportunity for the dissipation of heat from valves, pistons, and other critical engine parts, since a power stroke occurs on every other revolution; whereas, in the 2-stroke cycle engine, a power stroke occurs on every revolution of the crankshaft. In view of this, 4-stroke cycle engines can operate without experiencing as much overheating or valve damage. This can be somewhat compensated for in 2-stroke cycle engines through proper cooling system design.

i. Diesel fuels. The fuels used in modern high-speed internal combustion diesel engines are a product of the petroleum refining process. They are heavier than gasoline because they are obtained from the leftovers, or residue, of the crude oil after the more volatile fuels, such as gasoline and kerosene, have been removed. The large, slow running diesel engines used in stationary or marine installations will burn almost any grade of heavy fuel oil, but the high-speed diesel engines used in automotive installations require a fuel almost as light as kerosene. Although the diesel fuel is different from gasoline, its specification requirements are just as exacting as those of gasoline. Of the various properties to be considered in selecting a fuel for diesel engines, the most important are cleanliness, viscosity, and ignition quality.

(1) Cleanliness. Probably the most necessary property of a diesel fuel is cleanliness. The fuel should not contain more than a trace of foreign substance; otherwise, fuel pump and injector difficulties will occur. Diesel fuel, because it is heavier and more viscous than gasoline, will hold dirt in suspension for longer periods of time. Therefore, every precaution must be taken to keep dirt out of the fuel system or to eliminate it before it reaches the pumps. Water is more objectionable in diesel fuels than it is in gasoline because it will cause ragged operation and corrode the fuel system. The least amount of corrosion of the accurately machined surfaces in the injection equipment will cause it to become inoperative. Careful filtration is especially necessary to keep diesel engines efficient. Diesel fuels are more viscous than gasoline. They contain more gums and more abrasive particles, which may cause premature wear of the injection equipment. The abrasives may consist of material difficult to eliminate during the process of refining, or they may enter the fuel tank through careless refueling. Whatever the source, it is imperative that means be provided to protect the system from these abrasives. Most diesel engine designs include at least two filters in the fuel supply systems to protect the closely fitted parts in the pumps and nozzles. The primary (coarser) filter is usually located between the supply tank and the fuel supply pump. The secondary (finer) filter is found between the fuel supply pump and the injection pump. Additional filtering elements are frequently installed between the injection pump and the nozzle. Diesel fuel oil filters are referred to as full-flow filters, since all fuel must pass through the filters before reaching the injector pumps. Filters must be inspected regularly and cleaned or replaced if maximum efficiency is to be maintained. There are two types of fuel filters commonly used in the fuel supply systems of diesel engines — the metal-disk-type and the cloth-bag-type. A diesel oil filter usually incorporates an air vent or air bleed to release any air that might accumulate in the filter during operation.

(a) All metal-disk-type filters have a cleanable element. These filters are used as primary filters because the fine particles that may pass through them are not injurious to the supply pump, as they would be to the injection pump. After removing the shell, which acts as a settling chamber, the strainer assembly can be removed and cleaned with a suitable liquid cleaning solution. Compressed air should not be used on the strainer assembly disks. Some fuel filters incorporate a cleaning knife. Solids larger than 0.005 inch remain on the outside of the element, and the cleaning knife serves to scrape the deposits off the filtering disks. The solids fall to the bottom of the housing where they can be removed through the drain plug hole. A ball relief valve in the filter cover enables the fuel oil to bypass the filter element if the disks become clogged.

(b) The cloth-bag-type (fabric) filters, because of their greater filtering qualities, are used principally as main filters for protecting the fuel injection pump. Many of the filters in use are similar to the lubricating oil filter. In this type filter, the element is not cleanable and must be replaced. The filtering medium is a large bag of close, evenly woven, lintless, acid-resisting textile material. Maximum benefit is derived from the bag's large area by keeping the sides of the bag separated by a wire-screen mat. The screen is the same size as the bag, and the two are detachably fastened to a central feeding spool and wound around it. Layers of bag and screen are thus alternated through the winding, and the entire surface of the bag is available for filtering purposes. The fuel to be filtered flows from the filter inlet at the top, through the spool, and out the ports to the inside of the bag. The dirt, solids, abrasives, carbon, etc., are caught in the bag, and the clean fuel passes outward and to the filter outlet.

(2) Viscosity and pour point. The viscosity and pour point of a fuel indicate its fluidity. Viscosity is the term used to indicate the internal friction or resistance to flow of a liquid. It is measured in seconds, the time required for a measured quantity of liquid fuel at 100° F to pass through a calibrated hole in a viscometer. The lowest temperature at which fuel oil will just flow (under controlled test conditions) is called the pour point. It indicates the suitability of the fuel for cold weather engine operation, since the fuel must remain fluid in order to be handled by the fuel system. Unless arrangements are made for heating, the fuel must not be more viscous than 550 seconds at the lowest operating temperature, or it will not flow through the fuel system. While maximum viscosity is limited by handling considerations, minimum viscosity is also limited by injection system requirements. The fuel must have sufficient body to lubricate the closely fitted pump and nozzle plungers properly. In order to do this and to prevent wear, scoring, and sticking, the fuel should have a viscosity greater than 35 seconds at 100° F. The fuel must also be viscous enough to prevent leakage at the pump plungers and "dribbling" at the injection nozzle. Leakage occurs when the fuel viscosity is less than 34 or 38 seconds at 100° F depending upon the type, temperature, and pressure of the injection system. Fuel shipped from a refinery is usually free from water and sediment. Diesel fuel, being more viscous than gasoline, will hold dirt in suspension longer. As it is transferred from tank to tank from the refinery to the engine, it will sometimes pick up sufficient water and sediment to corrode the fuel pump parts or injection system parts. To prevent this, care must be exercised in handling fuel, and line fuel strainers must be adequate to remove any water or sediment which has found its way into the fuel. The filters, therefore, must be checked frequently. A fuel's viscosity also determines the size of the fuel-spray droplets which, in turn, governs the atomization and penetration qualities of the spray.

(3) Ignition quality.

(a) The ignition quality of a diesel fuel is its ability to ignite spontaneously (without mechanical assistance, such as a spark) under the conditions existing in the engine cylinder. The spontaneous ignition point of a fuel is a function of temperature, pressure, and time. A fuel with a good ignition quality (one that will ignite at low temperatures) is most desirable for diesel engines for several reasons. Smoking, knocking, and ease of starting are somewhat dependent on the ignition quality of the fuel. An engine will start if, after compression, the temperature in the engine cylinder is above the ignition temperature of the fuel. Compression temperature is related to outside air temperature; so, the lower the ignition temperature of the fuel, the lower the possible atmospheric temperature at which the engine will start. If the ignition temperature of a fuel is too high, the engine will smoke — particularly at light loads when engine temperatures are low. Diesel fuels (like gasoline) are composed of fractions or parts, each having different characteristics; some are light and volatile and others heavy and less volatile. The lighter parts will ignite at a lower temperature, while the heavier parts require a higher temperature to ignite. The ignition quality of diesel fuels is indicated by cetane numbers, just as octane numbers are used to indicate the antiknock quality of gasoline. The ignition quality of a diesel fuel is determined by comparing it with a standard reference fuel, according to the cetane number scale. To obtain the cetane number of a fuel, a special test engine is used. This engine, operating under controlled conditions and using a mixture of cetane that has good ignition qualities and alpha-methyl-naphthalene that has poor ignition qualities, is used to establish a standard of measurement.

(b) The cetane number of a fuel is the percentage of cetane that must be mixed with alpha-methyl-naphthalene in order to duplicate the ignition quality of the diesel fuel being tested. Thus, if a fuel has the same ignition quality as a reference fuel composed of 60 parts cetane and 40 parts alpha-methyl-naphthalene, the fuel has a cetane number of 60. The ignition quality most suited for any particular engine is best determined by trial, or the engine manufacturer might recommend the fuel most suited for his particular engine.

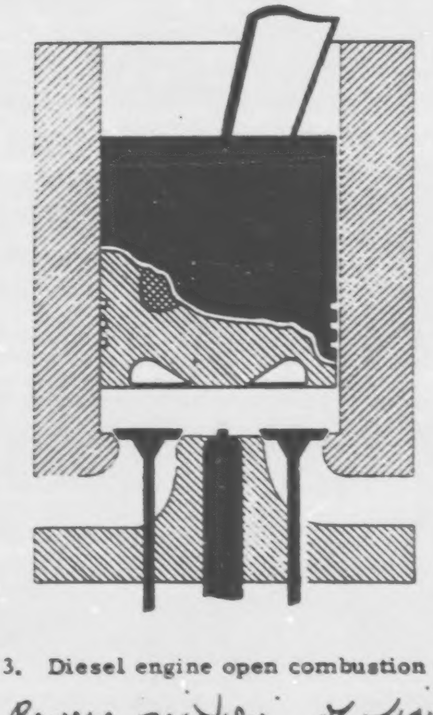
At present, most diesel engines require fuels within the range of 30 to 60 cetane numbers. Very little demand exists for fuels outside of this range. The recommendation of a fuel most suited for a particular engine requires consideration of more than one (good ignition quality) factor for good engine operation, such as load, engine speed, time and atmospheric temperature. The lower the atmospheric temperature, the lower the temperature will be in the engine combustion chamber. In extreme cold areas some type of special aid must be employed to get the engine started. This aid may be either the application of heat to the inlet manifolds or jackets to heat the air entering the engine cylinders, or the use of electrically heated glow-plugs which will raise the air temperature locally in the engine for starting only, or the use of an ether or other cartridge which provides a mixture ignitible at well below normal temperatures. The time factor could be incorrect due to combustion chamber design, speed of injection, plus other factors which will be noted later. A fuel having good ignition qualities will ignite and start to burn at the very beginning of injection and before all the fuel hits the air. It will continue to burn progressively as it is injected into the cylinder. Thus, this condition must exist to obtain maximum power and smooth engine operation and avoid detonation. Mainly, this is accomplished by combustion chamber, injection nozzle, and injection pump design.

(4) Knocking. It has been observed that compression ignition engines knock, particularly at light loads. This knock is believed to be due to the rapid burning of the charge of fuel accumulated during the delay period between the time of injection and ignition. When the fuel is injected, it must first vaporize, then superheat until it reaches the spontaneous-ignition temperature under the proper conditions to start combustion. Time is required for sufficient fuel molecules to go through this cycle to permit ignition. This time is called ignition lag or ignition delay. During this same time, other portions of the fuel are being injected and are going through the same phases, but behind the ignition portion. As the flame spreads from the point of ignition, appreciable portions of the charge reach their spontaneous ignition temperatures at practically the same instant. This rapid burning causes a very rapid increase in pressure, which is accompanied by a distinct and audible knock. Increasing the compression ratio will decrease the ignition lag and thereby decrease the tendency to knock; whereas, increasing the compression ratio in a gasoline engine (spark ignition) leads to preignition and tends to make detonation worse. Knocking in the diesel engine (compression ignition) is affected by a large number of factors besides compression ratio, however. The type of combustion chamber, airflow within the chamber, the type of nozzle, the injection pressure conditions, the fuel temperature, and the air temperature are all factors, as are the characteristics of the fuel itself. For these reasons, more can be done in the design of a diesel engine to make it operate smoothly without detonation, than can be done with the gasoline engine.

j. Types of combustion chamber. The fuel injected into the combustion space of a diesel engine must be thoroughly mixed with the compressed air and distributed as evenly as possible throughout the chamber. None of the liquid fuel should strike the chamber walls. It is essential that the shape of the combustion chamber and the characteristics of the injected fuel spray be closely related. There are many types of combustion chambers in use today, but they are all designed to produce one effect — to bring sufficient air into contact with the injected fuel to provide complete combustion at a constant rate. All modern combustion chamber designs may be classified under one of the following headings: open, precombustion, turbulence, or divided chambers. Designs which fall under two or more headings will be covered under the heading which is the most applicable.

(1) Open chamber. The open chamber (fig 3) is the simplest form of chamber. The fuel is injected directly into the combustion space at the top of the cylinder. The combustion space, formed by the top of the piston and the cylinder head, is shaped to provide a swirling action of the air as the piston comes up on the compression stroke. There are no special cells, pockets, or passages to aid the mixing of fuel and air. This type of chamber requires higher injection pressures and a greater degree of fuel atomization than is required by the other types to obtain the same degree of mixing. The open chamber design is used in the 2-stroke-cycle diesel engines found in several types of Army vehicles.

(2) Precombustion chamber. The precombustion chamber (fig 4) is an auxiliary chamber at the top of the cylinder. It is connected to the clearance volume above the piston through a restricted throat or passage. The precombustion chamber conditions the fuel for final combustion in the cylinder and distributes the fuel throughout the air in the cylinder in such a way that complete, clean burning of all the fuel is assured. On the compression stroke of the engine, air is forced into the precombustion chamber and, since the air is compressed, it becomes hot. At the beginning of injection this small chamber contains a definite volume of air. Combustion of the fuel actually starts in the precombustion chamber, since the fuel is injected into the chamber. Only a small part of the fuel is burned in this chamber because there is only a limited amount of oxygen present with which it can unite. The small predetermined amount that burns creates heat that, in turn, creates high pressure within the precombustion chamber; as injection continues, this high pressure forces the fuel at great velocity into the cylinder. There is ample oxygen present in the cylinder to burn all the fuel completely, regardless of the speed or load under which the engine is operating. Fuel injection pressures need not be as high with this type of chamber as in the open-type. A coarser spray is satisfactory because the function of the chamber is to vaporize the fuel further before it enters the cylinder.



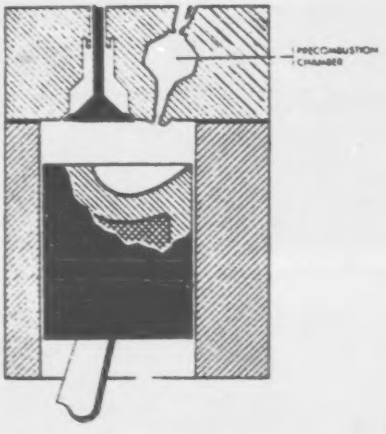


Figure 4. Diesel engine precombustion chamber.

Figure 3. Diesel engine open combustion chamber.

Reverse position of figure. Figure was printed upside down.

(3) Turbulence chamber. The turbulence chamber (fig 5) is similar in appearance to the precombustion chamber, but its function is different. There is very little clearance between the top of the piston and the head, so that a high percentage of the air between the piston and the cylinder head is forced into the turbulence chamber during the compression stroke. The chamber is usually spherical, and the opening through which the air must pass becomes smaller as the piston reaches the top of the stroke, thereby increasing the velocity of the air in the chamber. This turbulence speed is approximately 50 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is the greatest. This insures a thorough mixing of the fuel and the air, with the result that the greater part of combustion takes place in the turbulence chamber itself. The pressure created by the expansion of the burning gases is the force that drives the piston downward on the power stroke.

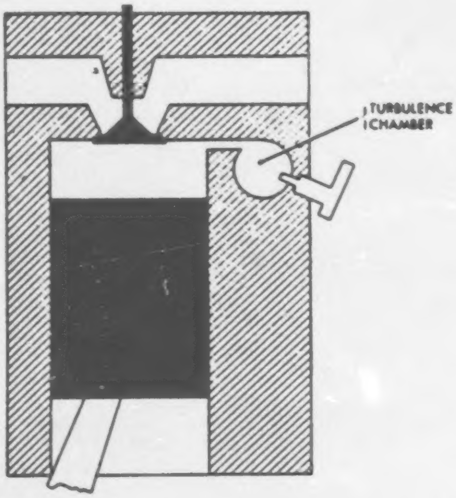
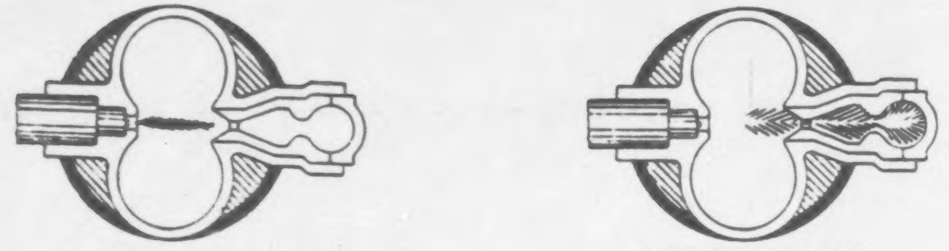


Figure 5. Diesel engine turbulence chamber.

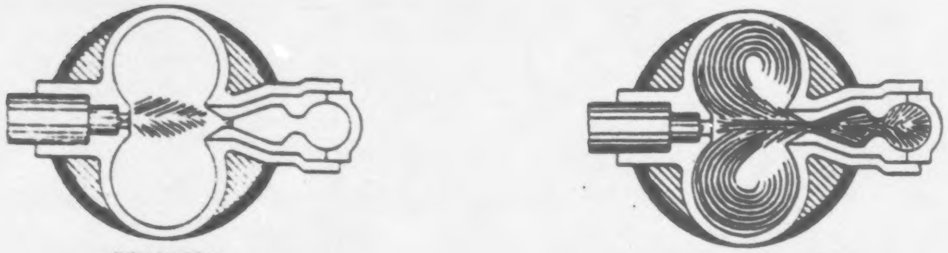
(4) Divided chamber.

(a) The divided chamber (fig 6), or combination precombustion chamber and turbulence chamber, probably is better known by the trade name, Lanova combustion chamber. Like the open chamber combustion system, the combustion is controlled. Like the turbulence-chamber-type, the Lanova system depends on a high degree of turbulence to promote thorough mixing and distribution of the fuel and air; but, unlike it, this entails no increase in pumping losses. Ninety percent of the combustion chamber is directly in the path of the in-and-out movement of the valves. The turbulence in the Lanova system is dependent upon the thermal expansion and not on engine speed, as are the other systems.



FUEL INJECTION

COMBUSTION IN ENERGY CELL



FUEL IGNITION

COMBUSTION IN MAIN CHAMBER

Figure 6. Lanova divided chamber - fuel combustion.

(b) Primarily, the Lanova system involves the combination of the figure-8-shaped combustion chamber, situated centrally over the piston, and a small air chamber, known as the energy cell. In its latest development, this energy cell is comprised of two separate chambers—an inner and an outer. The inner chamber, which is the smaller of the two, opens into the narrow throat between the two lobes of the main combustion chamber through a funnel-shaped venturi passage. The larger outer chamber communicates with the inner one through a second venturi. Directly opposite the energy cell is the injection nozzle.

(c) During the compression stroke, about 10 percent of the total compressed volume passes into the energy cell, the remainder staying in the figure-8-shaped combustion chamber. The fuel is injected in the form of a pencil stream that passes directly across the narrow throat of the combustion chamber, most of it penetrating into the energy cell. A small portion of the boundary layer follows the curvature of the combustion chamber lobes and swirls into vortexes within them. The fuel entering the energy cell is trapped, for the most part, in the small outer cell, but a small part passes into the larger outer cell where it meets a sufficient quantity of superheated air to explode violently. This explosion produces an extremely rapid rise in pressure within the steel energy cell, which blows the main body of the fuel lying in the inner cell back into the main combustion chamber, where it meets the main body of air. Here, owing to the shape of the chamber, it swirls around at an exceedingly high rate of turbulence, burning continuously as it leaves the energy cell. Owing to the restriction of the two venturis connecting the energy cells, the blowback of fuel into the combustion chamber is controlled so that this operation consumes an appreciable period of time, producing a prolonged and smooth combustion in which the rate of pressure rise on the piston is gradual.

k. Fuel injection principles.

(1) Methods. There are two methods of injecting the fuel against the air pressure in the cylinder of a diesel engine — air injection, where a blast of air from an external source forces a measured amount of fuel into the cylinder; and solid injection, where the fuel is forced into the cylinder by a direct pressure on the fuel itself. The discussion which follows will be limited to those systems utilizing solid injection, because the air injection system has been proved impractical for automotive installations.

(2) Fuel atomization and penetration. The fuel spray entering the combustion chamber must conform to the shape of the chamber so that the fuel particles will be well distributed and thoroughly mixed with the air. The shape of the spray is determined by the degree of atomization and penetration produced by the orifice through which the fuel enters the chamber. Atomization is the term used to denote the size of the drops into which the fuel is broken; whereas, penetration is the distance from the orifice which an oil drop attains at a given phase in the injection period. Roughly speaking, the penetration of a spray depends on the length of the nozzle orifice, the diameter of the orifice outlet, the viscosity of the fuel, and the pressure on the fuel. Penetration increases with the increasing ratio of the length of the orifice to its diameter; atomization, however, is increased by decreasing the ratio of the length of an orifice to its diameter. Since penetration and atomization are mutually opposed to each other, a compromise is necessary if uniform fuel distribution is to be obtained. The amount of pressure required for efficient injection is dependent on the pressure of the air in the combustion chamber, the size of the orifice, the shape of the combustion chamber, and the amount of turbulence produced in the combustion space.

(3) Function of injection system. The function of each system is to meter the fuel accurately, deliver equal amounts of fuel to all cylinders at a pressure high enough to insure atomization, and control the start, rate, and duration of injection.

Note. - Answer the questions below.

71. Why does the military desire a multifuel engine for use in ground equipment?

a. To reduce maintenance problems
b. To help overcome logistical fuel problems
c. To develop more horsepower per pound of engine

72. To comply with Army requirements, what is the maximum weight allowed, in pounds, per horsepower in a multifuel engine?

a. 6
b. 10
c. 12

73. What characteristic eliminated the gasoline engine during the selection of a multifuel test engine?

a. Excessive maintenance costs
b. Poor fuel economy
c. High manufacturing cost

85

74. What type engine may be classified as a true multifuel engine?

- a. Diesel, supercharged
- b. Internal combustion, magneto ignition
- c. Gas turbine, regenerative

75. What statement, pertaining to a comparison of the 2-stroke- and 4-stroke-cycle diesel engines, is true?

- a. Power stroke of the 2-stroke-cycle engine is longer
- b. Less air is available to the 4-stroke-cycle engine during intake
- c. Power stroke of the 4-stroke-cycle engine is longer

4. REASONS FOR SELECTING THE DIESEL ENGINE FOR CONVERSION TO A MULTIFUEL ENGINE.

a. First, there are intake and exhaust valves on each engine. The diesel engine uses an injector pump and/or a nozzle instead of a carburetor and does not employ spark plugs. Ignition in diesel engines is attained by compressing the air in the cylinder to a point where its temperature is greater than the self-ignition temperature of the fuel and, then, injecting fuel into the high temperature air where it ignites and burns. The expansion as a result of the burning fuel-air mixture produces the energy required to accomplish work. It is an established principle that as the compression ratio of an engine is raised, the efficiency increases accordingly. This means that more power can be obtained from the same amount of fuel. The economy of a diesel engine in comparison to an electrical ignition engine is well established. Experiments also proved that diesel engines would operate on such fuels as kerosene and JP-4.

b. Selection of the diesel engine for application to the multifuel principle still left certain unsolved problems.

(1) Should the engine be air-cooled or liquid-cooled?

(2) Should open chamber or auxiliary chamber be used?

(3) Should 2-cycle or 4-cycle principle be used?

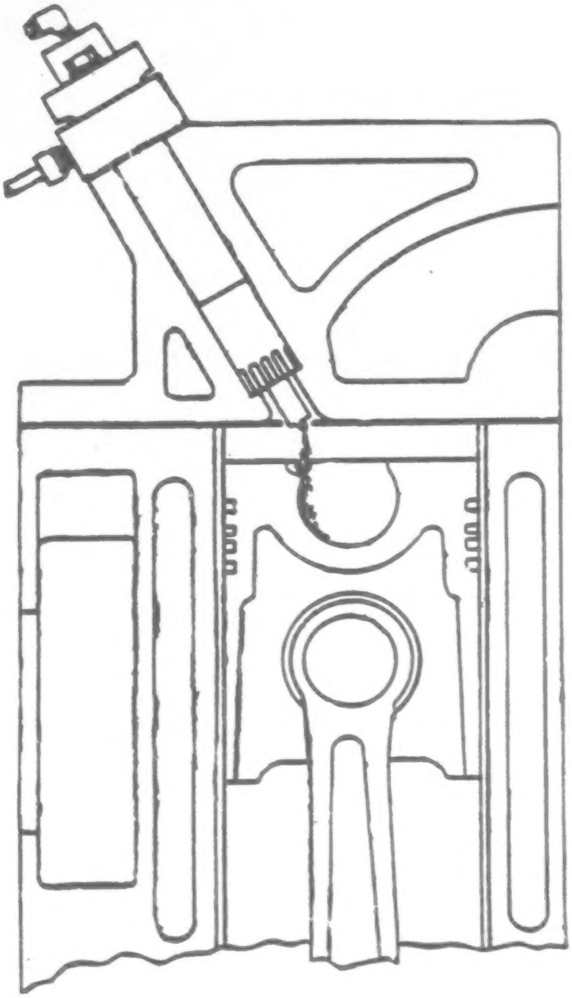
(4) How should control of combustion be maintained?

(5) How could fuel system efficiency be maintained?

5. MULTIFUEL ENGINE. The engine adopted by the U. S. Army was developed by Continental Motors.

a. The engine manufacturers adopted the MAN "Controlled Evaporation" principle. This combustion process was developed by Dr. Meurer of Germany, as a result of the Doctor's study of the reaction of kinetics involved in the diesel combustion process.

(1) This combustion priciple, which Continental calls hypercycle, differs from that of most other systems where the fuel is sprayed directly into the air in the combustion chamber. In this system, fuel is sprayed on the walls of the spherical combustion chamber in the direction of the air swirl (fig 7). Through the use of a special intake port the induction air is given a swirling motion, which persists into the combustion chamber and continues to supply oxygen to the slowly evaporating fuel. A small portion of the fuel, about 5 percent, breaks away from the jet before it hits the surface. This 5 percent goes through the normal ignition lag and combustion just as in a diesel engine. The remainder of the fuel, lying on the relatively cool piston and moving with the air, evaporates at a slower rate. It forms a combustible mixture whose composition has a higher self-ignition temperature than those mixtures formed by the same fuels when subjected to rapid evaporation in the presence of excess oxygen, as occurs in the normal diesel.



FUEL DEPOSITED ON WALLS OF THE SPHERICAL COMBUSTION
CHAMBER INSTEAD OF SPRAYED INTO AIR SPACE

Figure 7. Start of injection.

(2) Since this mixture has a higher self-ignition temperature, it will not auto-ignite, but must be ignited by the initial 5 percent of the fuel which is burning. Only the portion that is vaporized at any interval will burn. This quantity of fuel is never large enough to produce sudden high pressure rises.

(3) The burning of the fuel as evaporation takes place prevents accumulation of large amounts of vaporized fuel so that knocking does not occur when burning gasoline.

(4) Since the ability of any diesel engine to ignite fuel is dependent upon the compression temperature, it is important that certain minimum operating temperatures are maintained during light load and idle conditions, especially for arctic operation. For this reason a water-jacketed intake manifold maintained at a minimum of 150° F, by the water temperature thermostat, is used to increase induction-air temperatures in cold climates.

(5) Starting ability without outside aids in temperatures of -25° F is an essential requirement of military vehicles; therefore, an intake manifold flame heater is a standard item on this engine. Fuel, which is sprayed into the intake manifold by a special nozzle and ignited by a spark plug, burns a small portion of the oxygen in the induction system while the engine is being cranked. Induction air temperatures of approximately 300° F are obtained during cranking with the flame heater operating, allowing successful starts down to temperatures of 40 degrees below zero.

b. The multifuel engine, LDS-465-1 (fig 8 and 9) is a four-cycle, 6-cylinder in-line, water-cooled, cast-iron block, compression-ignition engine of conventional design, except for those features pertaining to the combustion system. Special consideration has been given to permit the use of a high compression ratio which, in this case, is 22:1, thereby developing firing pressures in the 2,000 PSI range.

(1) Such components as crankshaft, crankcase, and connecting rods are designed for firing pressures in the 2,000 PSI range. The crankshaft is especially rigid for good bearing conditions and reduced torsional vibration, which normally results from such high peak firing pressures.

(2) The crankcase (cylinder block) is a conventional 6-cylinder design made of cast iron, incorporating dry, cast-iron cylinder liners for ease of maintenance.

(3) The main bearing caps are provided with maximum support by recessing them into transverse webs, which are cast integrally with the crankcase.

(4) The overhead valves are operated by push rods from a gear driven camshaft. The helical gear train, located at the fan end of the engine, also drives the oil pump and fuel injection pump.

(5) The generator coolant pump and air compressor are belt driven from the fan end of the crankshaft.

(6) The hardened steel crankshaft is carried in 7 replaceable copper-lead alloy main bearings.

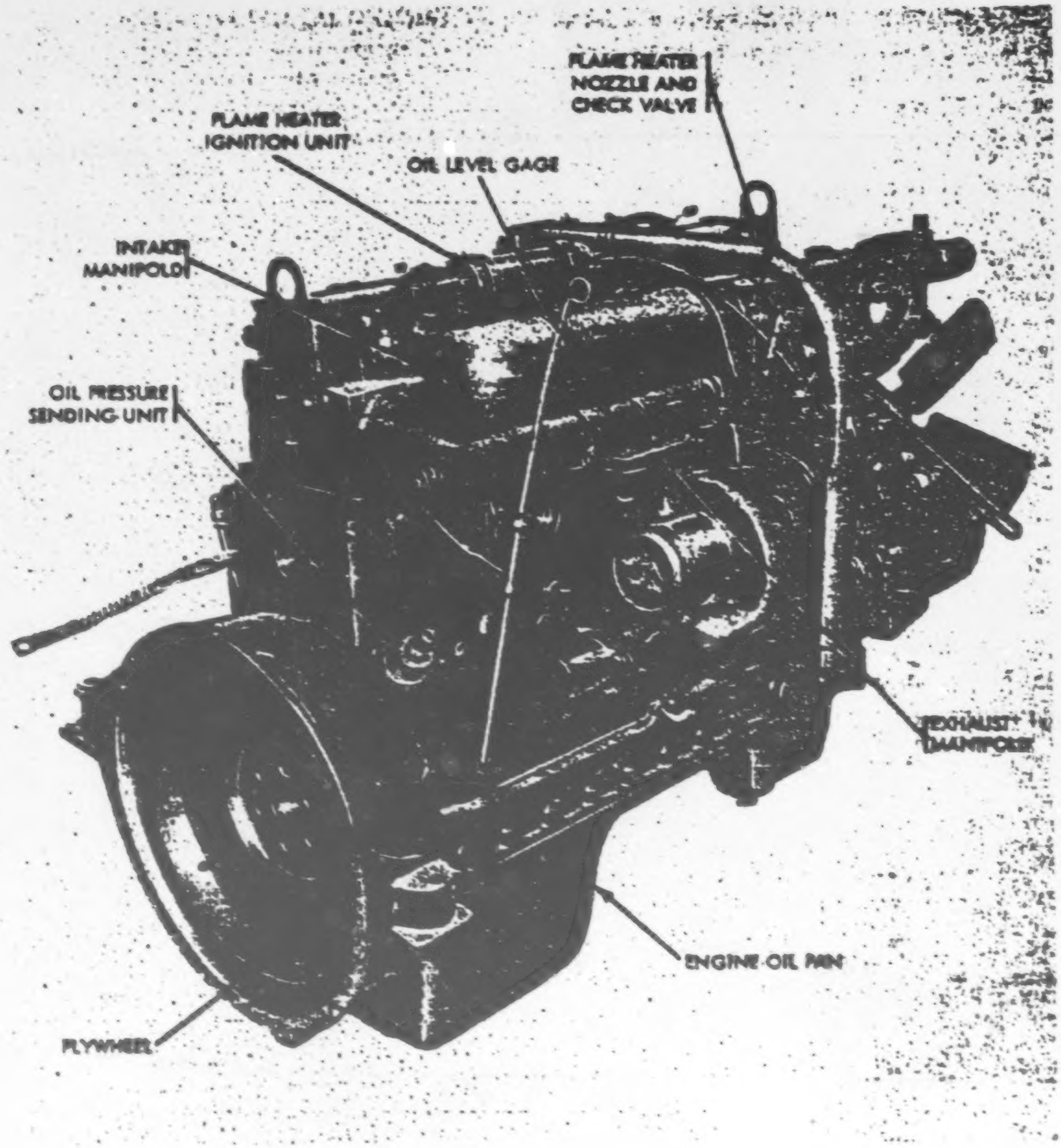

FLAME HEATER NOZZLE AND CHECK VALVE
FLAME HEATER IGNITION UNIT
OIL LEVEL GAGE
INTAKE MANIFOLD
OIL PRESSURE SENDING UNIT
EXHAUST MANIFOLD
ENGINE OIL PAN
FLYWHEEL

Figure 8. LDS-465-1 multifuel engine assembly.

(7) The tin-plated aluminum alloy forged pistons are cam ground to provide an accurate fit in the cylinder bore at operating temperatures. Each piston is fitted with 3 compression rings and 1 oil control ring. The success of the hypercycle process depends to a large degree on maintaining proper piston temperatures. In order to accomplish this, a separate gallery directs oil from the engine's oil reservoir to the underside of the pisto by means of suitable jets. These jets spray oil under the piston heads and spherical combustion chambers to keep them relatively cool.

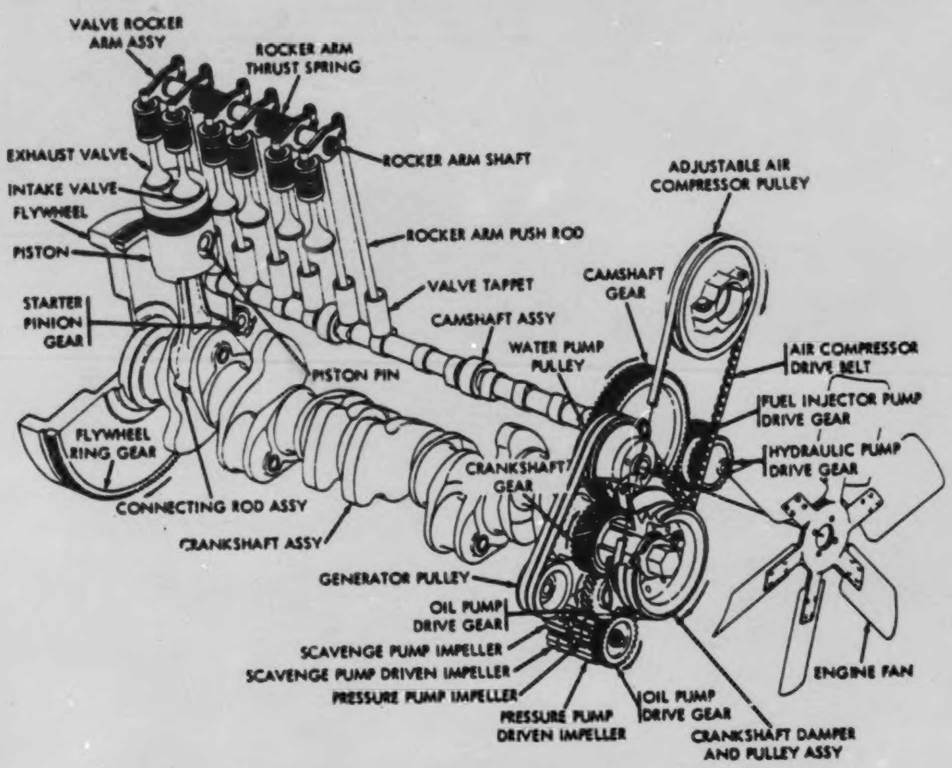

VALVE ROCKER ARM ASSY
ROCKER ARM THRUST SPRING
EXHAUST VALVE
INTAKE VALVE
FLYWHEEL
PISTON
STARTER PINION GEAR
FLYWHEEL RING GEAR
CONNECTING ROD ASSY
CRANKSHAFT ASSY
ROCKER ARM SHAFT
ROCKER ARM PUSH ROD
VALVE TAPPET
CAMSHAFT ASSY
PISTON PIN
WATER PUMP PULLEY
CAMSHAFT GEAR
ADJUSTABLE AIR COMPRESSOR PULLEY
AIR COMPRESSOR DRIVE BELT
FUEL INJECTOR PUMP DRIVE GEAR
HYDRAULIC PUMP DRIVE GEAR
CRANKSHAFT GEAR
GENERATOR PULLEY
OIL PUMP DRIVE GEAR
SCAVENGE PUMP IMPELLER
SCAVENGE PUMP DRIVEN IMPELLER
PRESSURE PUMP IMPELLER
PRESSURE PUMP DRIVEN IMPELLER
OIL PUMP DRIVE GEAR
CRANKSHAFT DAMPER AND PULLEY ASSY
ENGINE FAN

Figure 9. Engine gear train.

(8) The hypercycle combustion system requires nothing special in the way of a fuel injection system.

(a) The fuel system on this engine allows the engine to operate on various types and grades of fuel without adjusting the fuel injector pump. The fuel injector pump assembly is driven by the fuel injector pump driven gear, which meshes with the camshaft gear. The single-plunger distributor type pump is used to supply pressurized fuel to each individual fuel injector nozzle and holder assembly in the firing order sequence. The fuel injector pump advance unit automatically provides a gradual 8° advance of fuel injection timing over the engine speed range. A fuel density compensator on the pump automatically maintains constant full-power fuel flow regardless of the type or mixtures of fuel being used in the engine.

(b) The engine is moderately supercharged by an exhaust-driven turbocharger, which forces air into a water-jacketed, runner-type induction manifold. The purpose of the water jacketing is to provide heating of the induction air during cold weather operation.

c. In conclusion we have seen that multifuel capability can be built into compression ignition engines by taking the necessary measures to maintain combustion control and fuel system efficiency with all usable fuels. Other design problems and Army requirements such as lubrication, heat rejection, component life, fuel economy, and operation in extreme temperatures are solved by conventional methods. The LDS-465 multifuel engine is now incorporated in the truck, 5-ton, 6x6, and is a standard item of issue.

6. GAS TURBINE ENGINES.

a. For the purpose of evaluating the adaptability of gas turbines to military vehicles and to determine the advantages and disadvantages of such installations, the Army has obtained a number of gas turbines to test in military vehicles.

b. One of the major advantages of the gas turbine as opposed to the standard internal combustion engine is that its weight and bulk per unit of horsepower output is lower. Also, this engine can operate on a wide range of hydrocarbon fuel and maintain high torque at stall speeds.

c. The first of these units that was procured for testing in an Army vehicle was the GMT-305 gas turbine engine. This turbine is commercially available and is a regenerative-type free turbine with a rating of 206 horsepower at 3, 350 revolutions per minute (output shaft speed) at an ambient temperature of 80° F and 328 pound-feet of torque at the same speed.

d. The engine principles described thus far in this subcourse pertain to reciprocating engines. Reciprocating motion, as has been mentioned earlier, is an up-and-down or back-and-forth motion. The conventional gasoline and diesel engines use this reciprocating motion of the piston to turn the crankshaft. This principle you already understand.

(1) The principle of the turbine engine is somewhat different. In this engine the motion is rotary or circular with no up-and-down or back-and-forth motion required. In the reciprocating engine the up-and-down or back-and-forth motion is changed to rotary or circular motion through the crankshaft. In the turbine this circular motion is direct. Water and steam turbines have used this principle for a long time. The gas turbine is comparatively new but is becoming increasingly important.

(2) The gas turbine engine has no pistons or connecting rods. No water is required for its operation. In the turbine, fuel is burned in a chamber into which air has been pumped by an air compressor. The burning fuel and air create a high temperature, and the greatly expanded gases rush through the turbine. The whirlwind of the hot gases rushing through the turbine produces power. This is similar to the wind turning a windmill. The turbine is a wheel with vanes or blades. Figure 10 shows a turbine wheel. The vanes are somewhat like the blades of an ordinary fan. The push of the hot gases against these vanes of the turbine causes the wheel to turn and power is produced. The power produced may be in the form of direct power from a shaft through reduction gears that are turned by the turbine wheel. Figure 11 illustrates this type. Details of the compressor and turbine are not shown in the figure.

(3) The power may also be in the form of compressed air produced by the compressor. (The compressor itself is powered by the turbine.) In this system some of the compressed air is necessary to support combustion, but the excess amounts may be used for power.

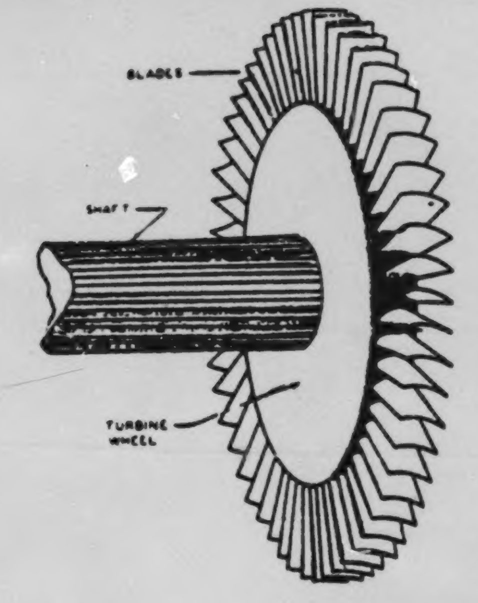

BLADES
SHAFT
TURBINE WHEEL

Figure 10. Turbine wheel.

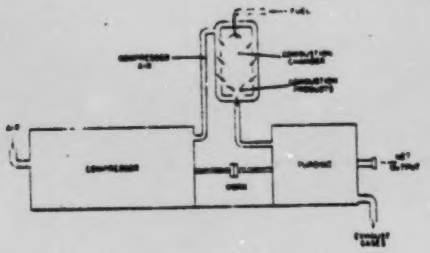


Figure 11. Schematic drawing of a gas-turbine engine.

(4) Any gas turbine consists basically of an air compressor (or compressors), a combustion section, and a turbine (or turbines). The engine functions by taking in atmospheric air and compressing it. Fuel is burned in the compressed air (fig 12), and the gases expand through a turbine wheel to drive the compressor. In some turbines, the power obtained is entirely through the shaft turned by the turbine; in others, power is in the form of air. All air excessive to the needs of the compressor is bled off. In the turbojet aircraft, the power is derived from the ejection of the gases in jet form. The gas turbine for ground use can be designed to burn almost any solid, liquid, or gas containing heat energy, provided the gases of combustion do not corrode or place deposits on the turbine parts. Gas-turbine engines do not have the problem of fuel knock or ignition timing. The main difficulty with combustion in the gas turbine is keeping the temperatures of the gases which are delivered to the turbine down to a point which the turbine can tolerate.

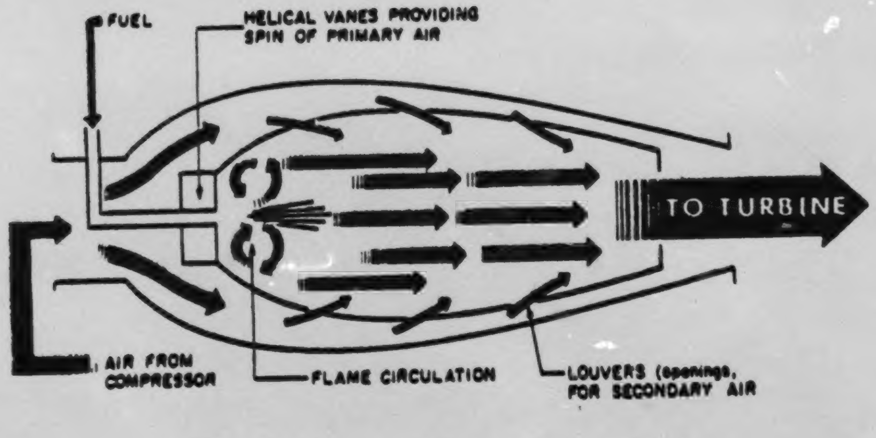

FUEL
HELICAL VANES PROVIDING SPIN OF PRIMARY AIR
TO TURBINE
AIR FROM COMPRESSOR
FLAME CIRCULATION
LOUVERS (openings, FOR SECONDARY AIR

Figure 12. Gas-turbine combustion chamber.

e. The GMT-305 gas turbine engine.

(1) The GMT-305 gas turbine is air cooled and it can operate on gasoline, diesel fuel, or kerosene. This engine is 36 inches long, 31 inches wide, and 26 inches high. Its dry weight is about 650 pounds. The present rated specific fuel consumption at full load is 0.57 pound of fuel burned per brake horsepower per hour.

(2) An explanation of the way in which the GMT-305 operates is best made by reference to the numerals shown in figure 13, which is a cutaway diagram of the GMT-305 gas turbine.

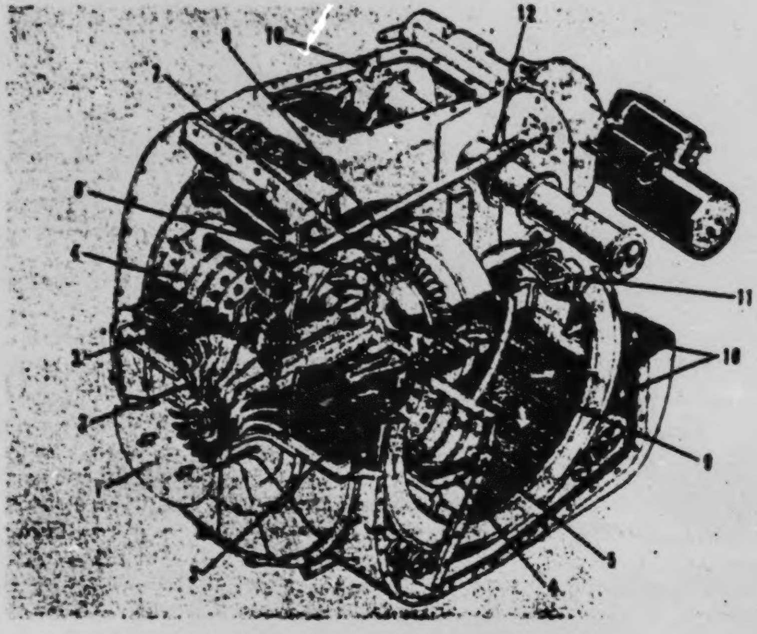


Figure 13. Cutaway diagram of GMT-305 gas turbine.

(a) No 1 - Atmospheric air enters the air inlet.

(b) No 2 - The air is compressed by the axial-flow compressor to above three atmospheres of pressure.

(c) No 3 - Rotating regenerators furnish heat to the compressed air as it passes through them.

(d) No 4 - The heated, compressed air enters the combustors.

(e) No 5 - Fuel is injected through nozzles into the combustors.

(f) No 6 - Gases resulting from the combustion of the fuel and air pass through the turbine vanes.

(g) No 7 - These gases first drive the "gasifier turbine," which powers the air compressor (shown in item 2).

(h) No 8 - The gases then drive the power turbine (note that the gasifier turbine and the power turbine are not connected mechanically).

(i) No 9 - The hot gas exhausted from the power turbine is cooled by the rotating regenerators (shown in item 3).

(j) No 10 - Exhaust gas at 300° to 500° F is directed out of the exhaust ports.

(k) No 11 - The power output shaft is driven from the power turbine through a single-stage reduction gear.

(l) No 12 - The accessory drive shaft is driven by the gasifier turbine through a set of reduction gears.

(3) Essentially, the gas turbine operates on the Joule cycle. This is the principle in which atmospheric air is compressed adiabatically (occurring without gain or loss of heat; a change of properties, such as volume and pressure of the contents of an enclosure, without exchange of heat between the enclosure and its surroundings), the combustion process adds heat at constant gas pressure, and the gases are expanded adiabatically through the turbine blades.

(a) The function of the regenerator is to recover heat from the turbine exhaust to improve efficiency.

(b) The rotating regenerators of the GMT-305 engine reduce exhaust noise, so that no muffler is required, and they also cool the exhaust gas.

(c) Neither radiator, fins, fans, nor plumbing are necessary for cooling the powerplant.

(d) Because the power turbine is connected pneumatically and not mechanically to the gasifier turbine and the air compressor, the power turbine acts as a built-in torque converter and maximum torque occurs when the power turbine is stalled.

(4) A GMT-305 gas turbine was installed in a modified, 90mm, full-tracked, self-propelled gun M56 and tested during the winter months at the U. S. Army Climatic Test Station, Fort Churchill, Canada.

(a) During a total 1,110 vehicle miles and 110 turbine hours, there were no major breakdowns, and 36 cold starting tests were successful. The formation of ice in the fuel lines was avoided by adding a pint of alcohol to each 20 gallons of fuel.

(b) These tests disclosed that a GMT-305 turbine equipped military vehicle would require unusually durable brakes to withstand continuous operation at various conditions of speed and torque.

1. This requirement is the result of inherent characteristics of the GMT-305 powerplant. Whereas, the acceleration or deceleration of the vehicle is controlled by changing the speed of the power turbine, the accelerator of the vehicle that regulates the rate of fuel flow to the combustors also controls the speed of the gasifier turbine.

2. Since the two turbines are only pneumatically connected, the speed of the output shaft of the power turbine is not regulated directly by the accelerator, and there is a consequent delay between movement of the accelerator and change in speed of the output shaft.

3. During the tests in extreme cold climate, it was found necessary to maintain the speed of the gasifier turbine at no less than 20,000 revolutions per minute for the best performance. Therefore, while applying the brakes to decelerate the vehicle, it was necessary to keep the accelerator depressed sufficiently to keep the gasifier turbine in the satisfactory range of performance of 20,000 revolutions per minute or more.

(c) The principal characteristics of this engine are as follows:

1. Model - GMT-305.

2. Type - free turbine, gas, regenerative.

3. Rated power - 206 hp @ 3,350 RPM (output shaft RPM).

4. Rated torque - 328 lb-ft @ 3,350 RPM.

5. Fuel requirement - gasoline (MIL-G-3050), compression-ignition (MIL-F-45121), diesel (VVF-800), or kerosene.

6. Coolant - air.

Note. - Answer the questions below.

76. Who developed the controlled evaporation principle used with the multifuel engine?

a. Joule
b. Dr. Otto
c. Dr. Meurer

77. What is done in the hypercycle that differs from other injection system principles?

a. The fuel is sprayed into the center of the compressed air
b. The fuel is injected into the manifold
c. The fuel is sprayed onto the walls of the combustion chamber

78. What is the function of the 5 percent of fuel that breaks away from the main charge during injection of the multifuel engine?

a. To ignite the main charge
b. To create a swirling motion to the intake air
c. To speed up ignition lag

79. What prevents the multifuel engine from knocking when burning low octane gasoline?

a. The mechanical ignition lag of 8°
b. The controlled accumulation of the vaporized fuel
c. The rapid condensation of the fuels

80. After the engine is started, what is used to increase the induction air temperature of the multifuel engine in cold climate?

a. Water jacketed intake manifold heater
b. Exhaust manifold flame heater
c. Intake manifold electric heater

81. What is the determining factor of any diesel engine as to its ability to ignite the injected fuel?

    a. The amount of fuel at injection
    b. The volume of air at injection
    c. The temperature of compressed air at injection

82. What is the compression ratio of the multifuel LDS-427-2 engine?

    a. 10:1
    b. 15:1
    c. 22:1

83. What components of the LDS-465-1 engine are designed to withstand high firing pressures?

    a. Crankshaft and connecting rods
    b. Cylinder block and camshaft
    c. Injector pump and camshaft

84. The helical gear train, located at the fan end of the multifuel engine, drives the oil pump and the

    a. fuel injector pump.
    b. generator coolant pump.
    c. air compressor.

85. How is the proper piston temperature maintained in the hypercycle process?

    a. By the use of high pressure water jackets
    b. By oil sprayed on the underside of the pistons
    c. By oil sprayed on the outer piston walls

86. What is an integral component of the injector pump assembly on the multifuel engine?

    a. Heater solenoid valve
    b. Secondary bypass line
    c. Fuel density compensator

87. What is an advantage of the gas turbine engine as opposed to the standard internal combustion engine?

    a. It requires less maintenance
    b. It is more reliable
    c. It can hold high torque at stall speeds

88. What furnishes heat to the compressed air in the GMT-305 gas turbine engine?

    a. Rotating regenerators
    b. Axial flow compressor
    c. Gasifier turbine

89. Into what portion of the GMT-305 gas turbine engine does the heated, compressed air enter?

    a. Regenerators
    b. Gasifier turbine
    c. Combustors

90. What cools the hot gas exhausted from the power turbine in the gas turbine engine?

    a. Axial flow compressor
    b. Rotating regenerators
    c. Gasifier turbine

SPECIAL TEXT

ST 9-177

FUEL INJECTION

JANUARY 1973

U. S. ARMY

8-4

This publication is provided for resident and extension course instruction at the U. S. Army Ordnance Center and School only. It reflects the current thought of this school and conforms to published Department of the Army doctrine as closely as possible.

U. S. ARMY ORDNANCE CENTER AND SCHOOL
ABERDEEN PROVING GROUND
MARYLAND

SPECIAL TEXT
No 9-177

US ARMY ORDNANCE CENTER AND SCHOOL
Aberdeen Proving Ground, Md., January 1973

FUEL INJECTION*

Prepared under the direction of the Commanding General,
US Army Ordnance Center and School

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*This text supersedes ST 9-177, dated September 1970.

99

SECTION I. GENERAL

1-1. PURPOSE AND SCOPE.

a. This text is published for use in resident instruction conducted by the US Arm, Ordnance Center and School. It is intended to provide information on gasoline and diesel engine injection systems to supplement the technical manuals in the field.

b. This text covers the principles of fuel injection and some types of injection systems. It describes the construction and operation of the Bosch, the Simmonds, and the Cummins fuel injection systems and provides a guide for their maintenance.

1-2. REFERENCES. The references are listed in the appendix.

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SECTION II. AIR-FUEL INDUCTION SYSTEMS

2-1. INTRODUCTION.

a. The process of metering and atomizing liquid fuel for burning in an internal combustion engine has, for many years, been accomplished by the engine carburetor. Carburetors have gone through various stages of development in attempts to improve their function. In the process of improving the fuel induction system the carburetor has changed from a relatively simple device to a complex mechanism. During recent developments to improve gasoline engine performance the inevitable has occurred - carburetors have been discarded in favor of an improved method of liquid fuel treatment for engine operation. This system is called fuel injection. It consists of a mechanical process of metering, timing, delivery, and atomization of fuel.

b. Application of fuel injection to gasoline engines is not new; it dates back to 35 years or more in some engine developments. Fuel injection began to appear in some gasoline aircraft engines as early as 1935. Diesel engines have utilized injection almost exclusively. The recent trend toward injected fuel systems will gain momentum and probably lead to elimination, to a great extent, of the carburetor in most gasoline engine applications. The rapidity of acceptance of fuel injection is best exemplified by the fact that the US Army has accepted fuel injections as standard equipment for most of its tracked vehicles.

2-2. AIR-FUEL INDUCTION SYSTEM REQUIREMENTS.

a. General. The purpose of the air-fuel induction system is to prepare, control, transport, and distribute the air-fuel mixture to the engine cylinders for final combustion. Preparation of fuel consists of metering the fuel for correct fuel-air ratio, atomization of the fuel to aid in mixing with air, and vaporization. Control is the process of varying the amount of air-fuel mixture that enters the engine cylinders. Transporting and distribution insure an adequate and equal (in quantity and quality) air-fuel mixture to each cylinder.

b. Requirements for maximum power.

(1) Various fuel and air ratios can be used in the gasoline internal combustion engine. A definite ratio is necessary to obtain maximum power, while a definite but different ratio is necessary for maximum fuel economy.

(2) Let us direct our attention just to the power or torque output of the engine at constant speed. Here the engine will induct a constant amount of air, limited directly by the piston displacement. If the fuel flow is increased by allowing a greater amount of fuel to be introduced, the power will be increased because of the liberation of additional chemical energy. This increase of power with the increase in fuel will continue until a point is reached where all the available air is effectively used for combustion. (When speaking of carburetion and fuel injection, the use of the term "air" denotes use of the oxygen in the air.) Since fuel flow can be regulated, but airflow is fixed by the design and displacement of the engine, it is the air supply and not the fuel that places a limit to the power output. Thus, in the ideal situation, maximum power is obtained when all the air in the cylinder is completely consumed. To achieve complete consumption of air, an excess of fuel, relative to the chemically correct mixture, must be used. This is due to several factors, the main ones being air and fuel are seldom perfectly mixed, fuel is never completely vaporized, and dilution of charge (fuel-air mixture) due to exhaust gas products.

c. Requirements for maximum economy. To achieve maximum fuel economy, the release of chemical energy per unit must be at its maximum. This condition is realized when the fuel is completely burned; therefore, an excess of air must be supplied. The air-fuel ratio will not depart far from the chemically correct mixture. Several factors act adversely to deter economy; some of these are incomplete mixing, atomization and vaporization, and, in some cases, inadequate air supply.

d. **Factors affecting both economy and power output.** It becomes apparent that an adequate air supply is essential to maximum economy and maximum power for a particular engine design. Good atomization and vaporization resulting in a homogeneous mixture also contribute to both power output and fuel economy.

2-3. CARBURETED AIR-FUEL INDUCTION SYSTEM.

a. **General.** Carburetors have been improved over the years and will, with proper intake manifold designs, provide excellent results over a broad operating range. However, the penalties involved in manifold design, by carburetor use, have caused engineers to look to other devices for solutions.

b. **Carburetor manifold problems.**

(1) Carburetor operation depends on decreasing the air pressure at the fuel discharge nozzle so that the atmospheric pressure will force fuel into the intake airstream. This change in pressure is accomplished by the use of a venturi to reduce the cross section area of the manifold (fig 2-1). In addition, the manifold size must be kept small enough to maintain sufficient air intake velocity to preclude the possibility of fuel condensation and fallout during transit to the cylinders. The limitations placed on manifold size by the venturi and need for air velocity reduces the amount of air available for combustion. This reduction in air supply becomes critical at higher engine speeds when time for scavenging and filling the combustion chamber is further limited. Carburetor system manifolds then must be a compromise, an attempt to satisfy two requirements, small enough to retain air velocity and large enough to satisfy engine breathing requirements.

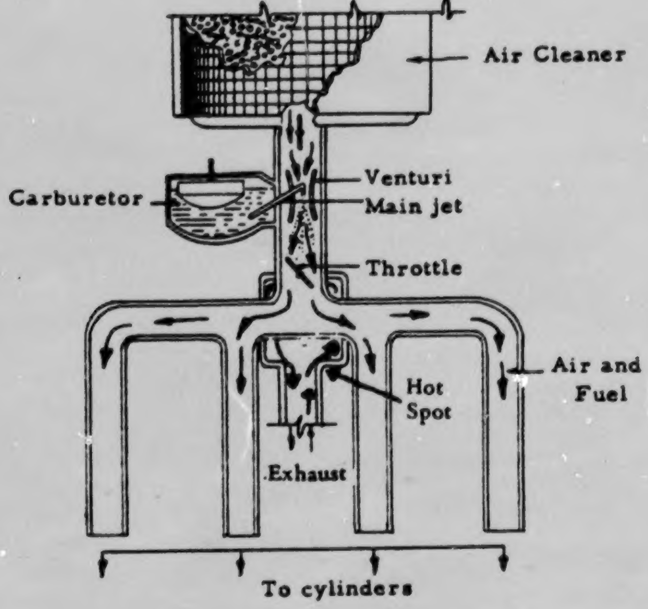

Figure 2-1. Typical carburetion system.

(2) The second problem area is that of transporting and distributing fuel. In the carbureted system the manifold transports and distributes fuel. Fuel is delivered to the manifold intake air only partly vaporized. The remainder is in the form of globules or film on the manifold wall. This situation is aggravated in cold weather operation with a cold manifold. Long manifolds with resultant airflow drag provide further opportunity for gas condensation and fallout. Long manifolds are also partly responsible for poor acceleration response due to delay of fuel in passing through the manifold. Curved manifold sections also contribute heavily to loss of fuel vaporization since the heavier fuel carried by the air strikes the walls and condenses. These manifold faults not only vary the quantity of the air-fuel charge delivered to each cylinder, but also vary the quality. Whereas the manifold can do a good job of distributing vaporized fuel, fuel in the liquid state cannot be properly distributed. The unequal distribution of fuel among the cylinders causes erratic operation and loss of power.

(3) To alleviate these manifold problems, hot spots are often used to heat the intake manifold to induce vaporization of fuel. (Hot spots are usually in the form of ducts that direct hot exhaust gases around the intake manifold to increase the temperature of the manifold (fig 2-1).) When intake manifold hot spots are used, the mixture expands, thus reducing the volumetric efficiency of the engine with a corresponding loss of torque and power. Heating the mixture also tends to cause preflame reactions and knock.

(4) In some cases, dual barrel carburetors or multiple carburetors have been employed to satisfy the engine's demand for greater air-fuel supply during high engine speeds. This has not proved completely satisfactory due to synchronization problems and excessive cost.

(5) Some characteristics of carbureted induction systems are particularly undesirable for military application. Carburetor icing, for example, is objectionable. This occurs when fuel is delivered into the airstream, causing a temperature drop due to vaporization of fuel. In cold weather operation ice will then form on the venturi and throttle plate. The ice formation impedes the flow of air to the detriment of proper engine operation. Military vehicles must be able to operate over rough terrain. Carburetors are designed to operate in a fixed position; extreme variations in terrain will affect carburetor operation. Military vehicles operate in extreme temperature ranges. Carbureted engines require an excessive warmup time, which is expensive in terms of fuel waste. Presence of the air-fuel mixture in an intake manifold invites backfire, which is hazardous as well as undesirable tactically.

SECTION III. SUPERCHARGER PRINCIPLES

3-1. GENERAL.

a. Supercharging, simply defined, is any assistance given to the engine intake process through the use of supplementary fans, blowers, and compressors. The primary reason for supercharging is that it greatly increases the power output of an engine with very little consequent increase in weight. The supercharger accomplishes this feat by increasing the overall efficiency of the engine. The overall efficiency of an internal combustion engine is affected by many factors, and the one we are concerned with here is volumetric efficiency—efficiency that is increased by supercharging. Volumetric efficiency can best be defined as the ratio of weights of the air actually drawn into the engine over a definite period of time to the quantity that would be inducted in the same length of time if it were not for the many losses present in any engine, such as leakages, friction losses, heat transfer losses, etc.

b. The term "volumetric efficiency" is slightly misleading when used in relation to internal combustion engines, since the efficiency is actually comprised of a ratio of weights and not volumes. When the term is used in connection with pumps and compressors, however, the ratio is of volumes; this is how the term evolved.

3-2. PRINCIPLES OF SUPERCHARGERS.

a. Properties of gases and their relation to supercharging.

(1) General. To understand the principles of supercharging, a general knowledge of mass, volume, and density, as applied to gases, is necessary. All matter can be classified into solids and fluids; and fluids may, in turn, be subdivided into liquids and gases. The weight of any substance is dependent upon its density, and the density of solids and liquids may be considered to be essentially constant. This is not the case with gases, however, for the density of gases is proportional to the pressure applied. In other words, when the pressure upon a gas is increased, its density also will increase; therefore, two identical volumes of gas under different pressures will not weigh the same. For example, at sea level about 13 cubic feet of air weighs 1 pound, but at high altitudes, where the atmospheric pressure is lower, the same 13 cubic feet of air would weigh a good deal less.

(2) Mass, weight, and volume. To the engineer, mass has a different meaning than weight; to the layman, in a general discussion such as this, the two may be considered to be the same. It is doubtful that there will be any confusion between weight and volume, but for the sake of clarity the difference between them is pointed out. Volume refers to the space occupied by matter, and weight refers to the force which a certain volume of matter would exert on a scale. From the last statement, it is obvious that the weight of any substance is directly proportional to its density and volume. The relationship between the properties discussed above will be explained in the following paragraphs.

(3) Boyle's law.

(a) Any gas may have its volume reduced by applying pressure to it. This phenomenon is known as compression. Boyle's law correlates the effect of pressure and volume upon an ideal gas whose temperature is held constant. A simple statement of this law is the volume of an ideal gas is inversely proportional to the pressure upon it, if the temperature is maintained constant.

Note. - An ideal gas is any gas that closely follows the relationship set up by Boyle. There is no actual ideal gas, but air conforms closely enough to the relationship that it may be considered ideal.

(b) Boyle's law, defined in (3)(a) above, is illustrated in figure 3-1. In this example we show two piston and cylinder arrangements that are identical in all respects, except that piston B has 200 pounds applied and piston A has only 100 pounds applied. The weight of the gas in both cylinders is 1 pound. In cylinder A the gas is under a pressure of 10 PSI and the volume is 100 cubic inches. In cylinder B the pressure is 20 PSI and the volume is now under 50 cubic inches. In other words, we now see that when the pressure is doubled, the volume is halved. Another change that has taken place with the addition of more pressure in cylinder B is that the density of the gas has been doubled, or, stated in a different way, we now have a mixture that has twice as much weight for every unit of volume.

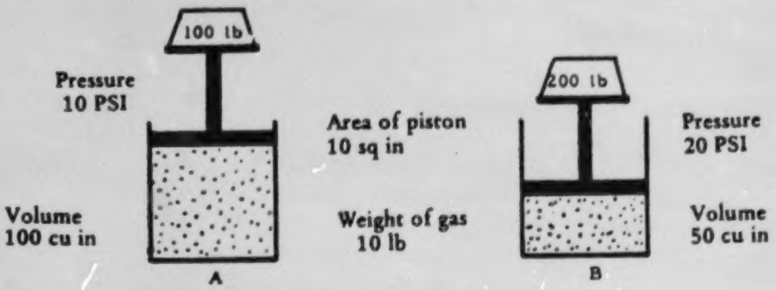

Figure 3-1. Boyle's law.

b. **Air induction in unsupercharged engines (normally aspirated).** The power developed by a normally aspirated internal combustion engine is largely dependent upon the density of the air inducted into the engine. In a normally aspirated engine, the air is drawn into the cylinder on the intake stroke with a force acting upon the gas equal to the pressure difference between the atmosphere and the cylinder pressure. The cylinder pressure approaches that of a perfect vacuum, which is zero pressure, and atmospheric pressure is about 15 PSI. Therefore, the pressure forcing the air into the cylinder is about 15 PSI (15 PSI minus 0 PSI = 15 PSI). Since the volume (displacement) of an engine is constant, we are limited in obtaining a high density air charge. The highest density we can obtain (during intake) is air at the same density as atmospheric air density. It was previously mentioned that the pressure acting upon the air is 15 PSI; this would be true if it were not for certain inherent losses prevalent in internal combustion engines. A few of these losses are leakage past the piston, preventing us from creating a perfect vacuum; pressure drops across restrictions in the manifold; leakage in the valves; and the heating of the air as it enters the manifold, which tends to expand the gas and decrease its density. All of these losses add up to one thing: it is hard for our engine to breathe. This difficulty in breathing causes slow response when the accelerator is depressed and a reduction in torque output before maximum power output is obtained. As the engine speed is increased, the breathing of the engine becomes increasingly difficult, since each cylinder has a much shorter time in which to fill itself with fuel-air mixture.

c. **Air induction in supercharged engines.** We previously explained the importance of volumetric efficiency to an internal combustion engine, and in the last paragraph we discussed the problem of breathing. With these two discussions in mind, it is not difficult to see that we could increase the density of the air entering our engine if we could only increase the pressure forcing the air into the engine. Increasing the density of the air would allow us to burn more fuel effectively and, therefore, increase our power output. This is precisely what is done in a supercharged engine. A supercharger is essentially a pump whose main function is to compress the air or air-fuel mixture in order to increase the density of the charge (fig 3-2). In summary then, a supercharger increases the power output in two ways:

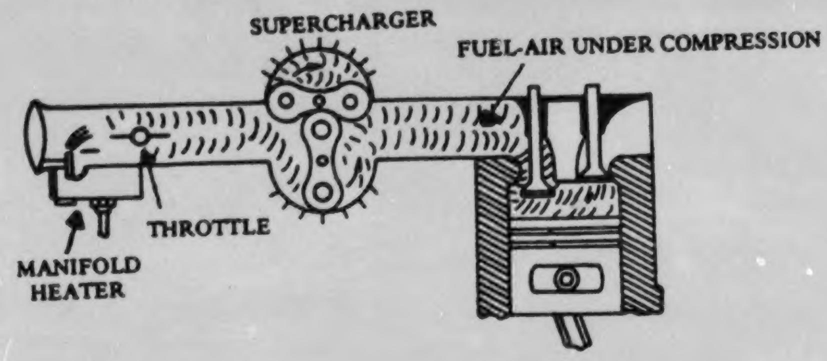

Figure 3-2. Supercharged engine.

(1) It increases the density of the fuel-air mixture (charge) delivered to the cylinders of the engine.

(2) It increases the maximum compression pressure. The compression ratio for any engine is constant; hence, the greater the pressure at the beginning of the compression stroke, the greater will be the pressure at the end of the stroke (maximum compression pressure is reached at the end of the compression stroke). This higher compression pressure increases the power output of the engine because the burning temperature of the gases is higher and, therefore, more energy is released per stroke of the engine.

d. **Horsepower to intake manifold pressure relationship (for supercharged engines only).** The relationship between the intake manifold pressure and the power output for a particular supercharged engine is shown on the graph in figure 3-3, where the intake manifold pressure in inches or mercury (Hg) is plotted horizontally and the horsepower is plotted vertically. By referring to a manifold pressure of 30 inches Hg and then following this vertical line up to its intersection with the plotted curve, we see that the power output for this engine is 550 horsepower at a manifold pressure of 30 inches Hg. (We previously stated that atmospheric pressure is about 15 PSI and this is approximately equal to 30 inches Hg.) The reason we point out the power output at 30 inches Hg is because this is the theoretical maximum horsepower this engine would develop if it were not supercharged. Remember, we previously said that the pressure differential approaches a maximum of 15 PSI in a normally aspirated engine. As is obvious from the graph (fig 3-3), the power output greatly exceeds 550 horsepower—this additional power is obtained by supercharging. It may appear that the output of the engine could be increased indefinitely by merely increasing the manifold pressure. This is not true because of the mechanical limitations of the engine itself. If this pressure became too high, the engine would become permanently damaged or, at the very least, would have its life considerably shortened. Another effect of the increasing manifold pressure is an increase in cylinder head temperature which could easily cause preignition, detonation, and valve burning. To compensate for the increase in temperature, cooling devices are sometimes used, such as sodium filled valves and heat exchangers.

e. **Advantages of superchargers.**

(1) Increase the power output of the engine with negligible increases in engine weight.

(2) Improve the torque output of the engine at higher RPM.

(3) Provide better response to throttle position.

(4) Provide better atomization and vaporization of the fuel-air mixture.

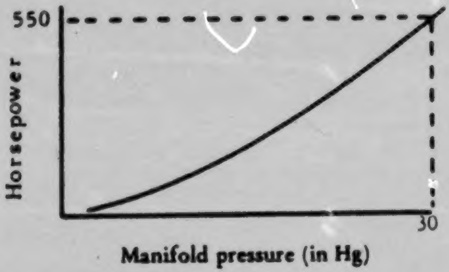

Figure 3-3. Horsepower to manifold pressure relationship.

f. Disadvantages of superchargers.

(1) Supercharger equipped engines are more expensive.

(2) The engine's maintenance burden is increased by the supercharger's complexity. The impeller (rotating member) is a highly machined and carefully balanced part and will stand very little abuse. A slight nick in this part will cause an unbalance—the blower will not operate at high speeds without excessive vibration and possible damage.

(3) The supercharger requires a large amount of power to drive it and this is compensated by the increased output added to the engine. But a supercharged engine is not very economical with respect to fuel consumption.

3-3. TYPES OF SUPERCHARGER SYSTEMS AND PUMPS.

a. Type of drives. Two means of driving supercharger pumps have been used. In one system, escaping exhaust gas is used to drive a turbine that is coupled to a supercharger impeller pump; this is called a turbosupercharger. The second method, and most common, is the mechanical drive, which is powered by a gear train from the engine.

b. Location of pump. Supercharger systems also vary as to location of the pump. When the pump is located between the carburetor and the manifold, it is called an internal system. When the pump is located in the air induction system in front of the carburetor, it is called an external system. In the first system the supercharger provides the advantage of additional fuel atomization. In the external system the air intake is increased, since no fuel is present when the air is compressed.

c. Single stage and two stage. In the single stage the system has but one pump. In the two stage two impellers are used in tandem to increase pressure. In the two stage it is necessary to have a cooling device located between the stages, since air temperature rises when compression occurs and, hence, the air density would decrease. Two-stage superchargers are sometimes found in aircraft engines but are not commonly found in automotive engines.

d. Two speeds. Superchargers with two-speed ratios are sometimes used on aircraft engines to compensate for differences in density of air at different altitudes. In automotive vehicles, superchargers are normally of single speed (ratio). In automotive engines, the speed of the supercharger will vary only with engine RPM—there is no gear ratio change.

e. Types of pumps (compressors).

(1) General. There are four basic types of compressors: diaphragm, reciprocating, rotary, and centrifugal. For purposes of supercharging, the diaphragm and reciprocating types can be readily eliminated because of the limited amount of air that they can handle. The rotary and centrifugal compressors have no reciprocating parts; thus, speeds can be high and large volumes of air can be handled per unit of time. It is for this reason that only rotating compressors, of which rotary and centrifugal are types, can be used for supercharging.

(2) Rotary compressors. Two common types of rotary compressors are the sliding vane type and the roots type. Both may be classed as positive displacement types; that is, a volume of air is trapped, and, leakages being neglected, all of it is pushed out by a definite movement of a part of the compressor.

(a) Sliding vane compressor (fig 3-4). As the rotor is eccentric to its casing, rotation causes the vanes to move in and out of their slots in the rotor, with centrifugal force holding them in or out by means of an eccentric. Note that there is a definite amount of compression because there is a definite change in the volume of the space between any two vanes as they are rotated from the inlet position to the discharge position. Because of the inertia of the vanes, the speed of the vane type is not as high as that of some other type, but is sufficiently high to be able to handle a much greater volume of air than a reciprocating compressor of the same bulk. In addition, the vane type has a tendency toward air leak around the vanes and toward excessive friction between the vanes and the rotor and between the vanes and casing. In spite of these drawbacks, the vane type is used, to a large extent, for compression of air in amounts up to 2,000 cubic feet per minute and for pressures up to 30 PSI.

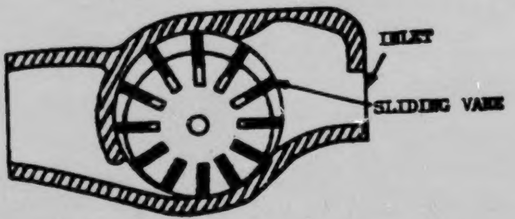

Figure 3-4. Vane type pump.

(b) Roots compressor (fig 3-5). The roots pump has two double-lobed impellers turning in opposite directions on parallel shafts inside the housing. The impellers roll together except for small clearances, alternately trapping the incoming air or air-fuel mixture and forcing it through the outlet. Since there is no change in volume of the space between the impeller and casing, the air is not compressed as it is carried around. When the top edge of the impeller passes the edge of the discharge, part backflow of air from the discharge space will occur until the pressure in the space between the impeller and the casing reaches the discharge pressures. It is used to a large extent for supercharging diesel engines.

(3) Centrifugal compressor (fig 3-6). The centrifugal supercharger is a non-positive displacement type compressor of high output capacity. All supercharged Army engines employ the centrifugal type supercharger. In this supercharger the impeller is installed in the inlet from the carburetor. It has very small clearances and usually is made of an aluminum-alloy forging which is designed to withstand high centrifugal forces of rotation and is balanced accurately to reduce vibration. The radial vanes of the impeller catch the fuel-air mixture from the carburetor and are curved in the direction of rotation to receive the fuel-air mixture without excessive shock or friction; thus, insuring smooth operation. Then the air is centrifugally forced through the radial passageway formed by the vanes. Due to centrifugal action, the air is whirled from the center outward, compressing the air progressively higher at each succeeding radius while allowing air to rush in to fill the void at the center. Note that compression of the air enables it to occupy a progressively small volume as it travels from the hub, although the passageway may diverge and offer a larger flow area at the perimeter. For this reason, the relative velocity of the air can decrease in passing from the hub to the perimeter. This decrease of velocity with consequent rise in pressure is called diffuser compression. The air leaving the impeller has a high absolute velocity due to the rotation of the impeller and centrifugal force action. This high velocity is reduced when the air leaves the impeller to enter the stationary diffuser vanes with a consequent increase in pressure. Actually, there are three steps in compression in a centrifugal supercharger due to centrifugal action, diverging contour at outer perimeter, and action of diffuser plate. One of the characteristics that is associated with the centrifugal superchargers is surging. This action occurs when the air at outlet pressure exceeds a point of compression for which the compressor is designed and causes air to surge back through the compressor. But with this pressure relief, the compressor responds by attempting to increase its pressure ratio and, again, a back surge is experienced. Thus, a high frequency surge of air back and forth in the compressor will occur. This is of negligible importance to conventional reciprocating engines but is problematical when applied to the gas turbines or jet propulsion. This problem is overcome in gas turbines by using axial flow compressors.

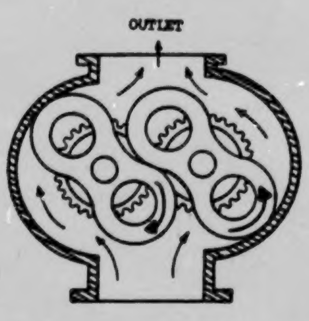

Figure 3-5. Roots type pump.

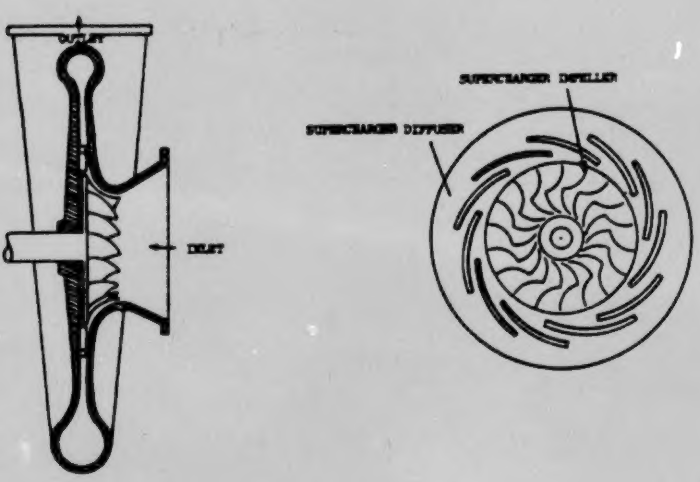

Figure 3-6. Centrifugal pump.

(4) Axial flow compressors (fig 3-7). Axial flow compressors consist of multiple rotors mounted on a common shaft separated by stators that are fixed to the compressor housing. The surface area of the rotor blades decreases progressively from intake to outlet. Compression is achieved in easy stages, increasing as air passes toward the outlet, thus reducing or eliminating the blow back or surge back through the compressor.

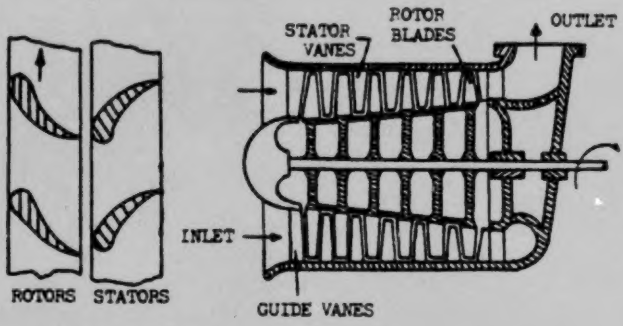
STATOR VANES
ROTOR BLADES
OUTLET
INLET
ROTORS
STATORS
GUIDE VANES

Figure 3-7. Axial flow compressor.

SECTION IV. FUEL INJECTION SYSTEM PRINCIPLES

4-1. GENERAL. With all the problems inherent in the carbureted fuel systems it can readily be seen why engineers turned to fuel injection systems for a possible solution to some of these problems. While the fuel injection system is not a panacea for all induction system problems, it does eliminate many of the more troublesome features of carbureted system intake manifold design.

4-2. FUEL INJECTION AND DIESEL ENGINES.

a. **General.** One of the earliest and most common applications of fuel injection systems has been in the compression-ignited engine (diesel engine). In the diesel engine, fuel is put under pressure by means of a mechanical pump. Fuel is metered mechanically, either within the pump or in a separate metering device. The fuel charge is distributed to the cylinders at intervals timed to the compression stroke and is injected, under high pressure, into the combustion chamber. Fuel injected into the highly compressed air of the combustion chamber causes ignition to occur. An excess of air is available at all times, since air is not throttled. Engine output depends only on the amount of fuel metered into the cylinder combustion chamber. Diesel engines can use a less volatile fuel since fuel is mechanically atomized and vapor is not necessary for starting.

b. **Advantages.** The advantages of diesel engines are many. They include:

(1) Fuel economy.

(2) Fuel less flammable.

(3) No electrical ignition required.

(4) Better low-speed torque.

(5) No carbon monoxide in exhaust gases.

c. **Disadvantages.** Diesel engines have their disadvantages too. Some of these disadvantages can be overcome at the expense of some of the advantages. The most notable disadvantages are:

(1) Excessive weight.

(2) High initial cost.

(3) Starting rather difficult.

(4) Greater maintenance cost.

4-3. FUEL INJECTED GASOLINE ENGINES.

a. **General.** In gasoline engines, the fuel is injected in measured quantities to the cylinders. Measuring, distribution, and atomization are performed mechanically (fig 4-1). The intake manifold has only one function—to provide free flow of air to the cylinder combustion chamber. However, the air intake is still throttled to control engine output, and ignition is still accomplished by electrical spark. Unlike the diesel, the gasoline injected engine must maintain a close air-fuel ratio to sustain combustion at varying load and speed conditions. There is no one single type of injection system. Systems vary as to type of pump, type of distribution systems, and in methods of controlling metering of fuel.

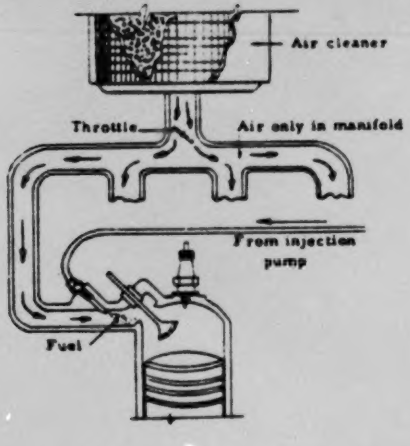

Figure 4-1. Typical injection system.

b. Types of fuel injection systems for gasoline engines.

(1) **General.** Classification of fuel injection pump and distribution systems may be made by four broad areas. A discussion of the basic systems follows. It should be remembered that although these are the basic systems, variations of each or combinations of some may be found in application. The basic systems are:

(a) Timed injection, independent distribution.

(b) Timed injection, common ratio.

(c) Continuous flow.

(d) Injection carburetion.

(2) **Timed injection, independent distribution.**

(a) This system involves a multiple unit pump that measures and injects fuel into lines at intervals timed by a distributor mechanism to coincide with the intake stroke of various cylinders (fig 4-2). The fuel then passes under relatively high pressure through independent lines to each cylinder. This allows the injector nozzles to be treated as an accessory unit. The nozzles are spring-loaded and will discharge an atomized spray of fuel when pressure in the line overcomes spring pressure. Spring-loaded discharge nozzles act to minimize fuel inertia problems by maintaining fuel in the lines under pressure during the noninjection period.

(b) The nozzles may discharge either in the intake port, manifold, or combustion chamber in any of the varied timed injection systems (fig 4-3). Generally, it is preferred to inject the fuel into the intake port. The finely atomized particles of fuel are sprayed on the head of the hot intake valve. This causes the fuel to vaporize. The vaporized fuel is then drawn into the combustion chamber on the intake stroke. This eliminates problems that are common to combustion chamber injection such as (1) high combustion chamber temperatures, (2) higher fuel pressures, and (3) clogging. Port injection is quite satisfactory for engines operating below 5,000 RPM. Above this range, timing of injection must be very accurate and short since the time the intake valve is open is very brief. This one reason why high-speed racing cars use combustion chamber injection in which there is no limitation of fuel intake time at high speeds.

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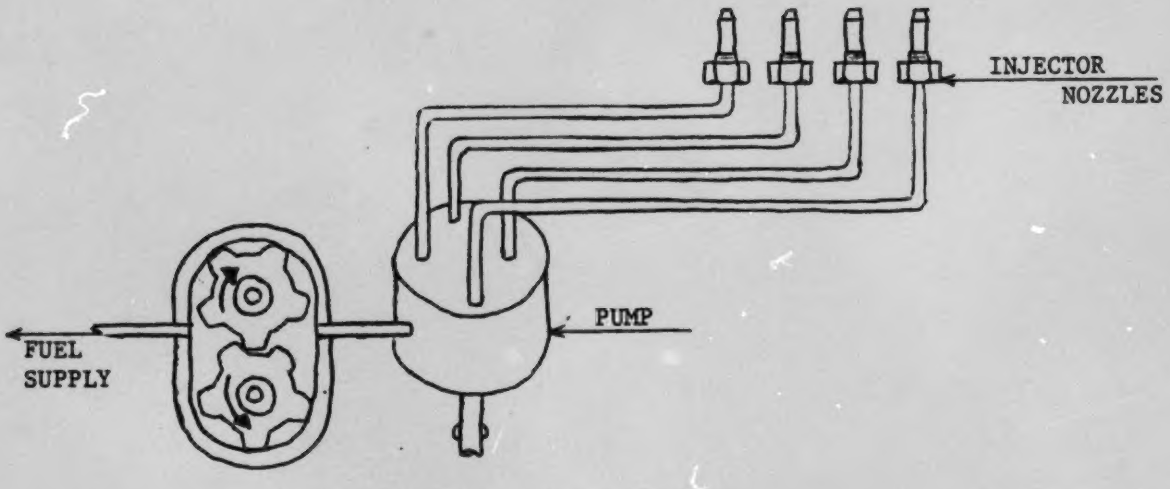
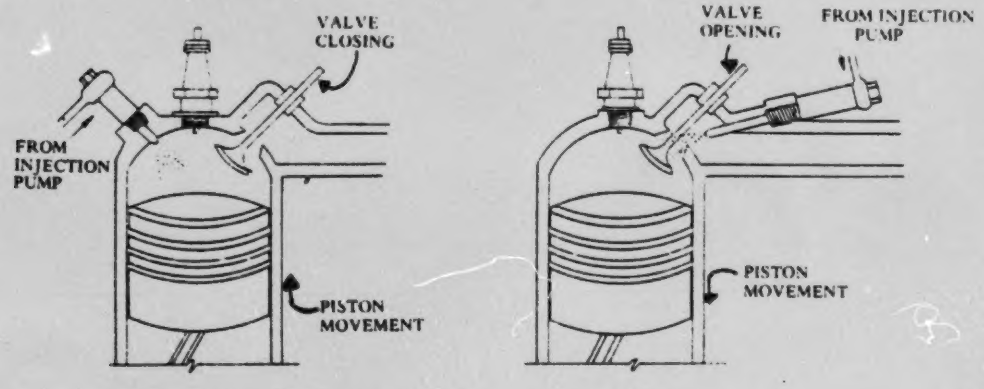


Figure 4-2. Timed Injection.

(c) Timed fuel injection with independent lines and spring-loaded nozzles is the type of injection system currently used by most US Army tracked vehicles. In this system fuel is injected into the intake port.



Combustion chamber injection

Intake port injection

Figure 4-3. Combustion chamber and intake port injection.

(3) Timed injection, common rail distribution. Fuel is delivered under a moderate pressure by a common line to spray nozzles in each cylinder (fig 4-4). The injector nozzles are, in effect, plunger-type pumps actuated by cams or, in some cases, solenoids that actuate the pumps at proper intervals. Actuation of the injector nozzles by camshaft has proved rather expensive. Solenoid actuation has achieved considerable acceptance. The primary objection to this type system is that it is difficult to vary fuel input uniformly among all cylinders.

(4) Continuous flow injection (fig 4-5). Some of the problems of timed injected systems and cost can be reduced by use of a continuous nontimed injection. In this system the fuel is delivered mostly during the interval between intake strokes of the engine cycle. The air-fuel charge is drawn into the cylinder when the intake valve opens on the intake stroke. The system is free of fuel line inertia problems; however, the fuel metering orifices must be extremely small because fuel is constantly dribbling in. This system is quite low in cost while retaining many of the advantages of injection.

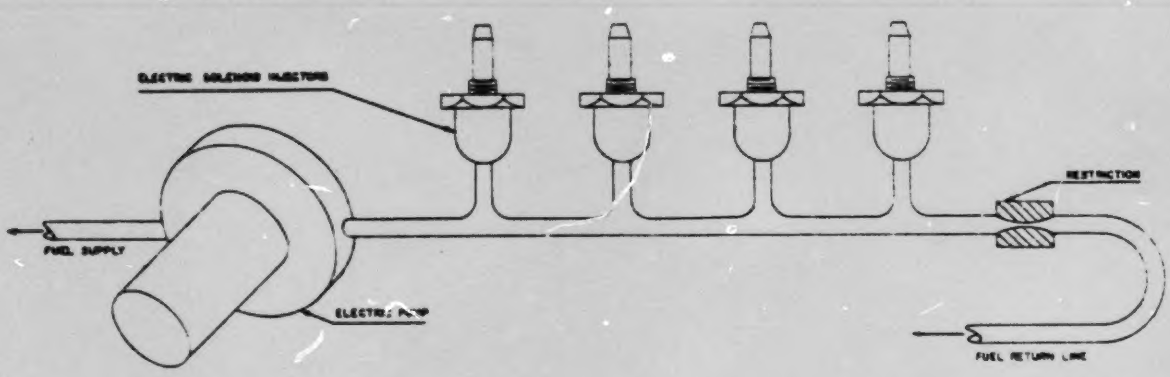

ELECTRIC SOLENOID INJECTORS
RESTRICTION
FUEL SUPPLY
ELECTRIC PUMP
FUEL RETURN LINE

Figure 4-4. Timed injection, common rail

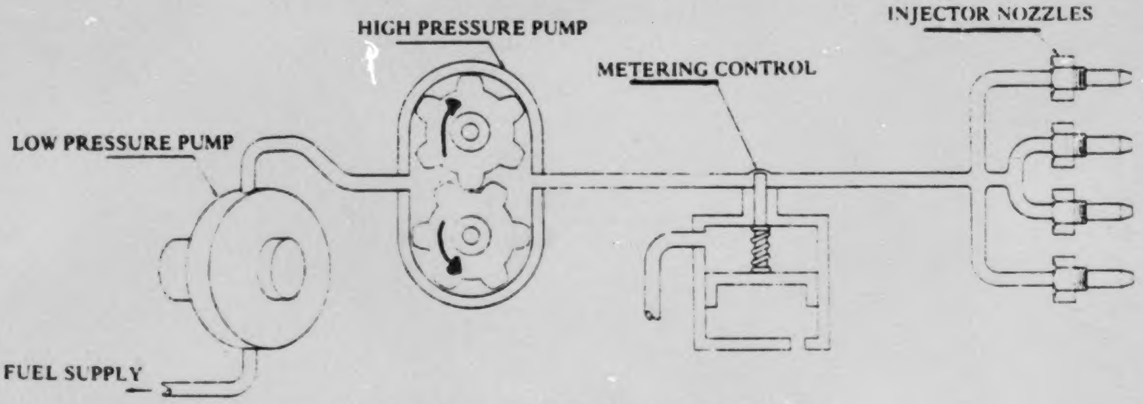

HIGH PRESSURE PUMP
INJECTOR NOZZLES
METERING CONTROL
LOW PRESSURE PUMP
FUEL SUPPLY

Figure 4-5. Continuous flow injection.

(5) **Injection carburetor system.** Conventional carburetors meter fuel and deliver it at the same pressure potential and at almost the same point in the airstream. Separation of these two functions is accomplished by the injection carburetor. In the injected carburetor positive atomization is possible because the fuel is atomized mechanically. Considerable performance improvement results when the fuel metering force is amplified and the freedom of delivery to any point in the system is attained by injection. Fuel injection's positive atomization is also helpful in improving performance. In this system fuel is supplied to the carburetor pump under moderate pressure. The fuel is then metered and sent to a supplementary pump that repressurizes it. The discharge of fuel occurs above the throttle to eliminate the problem of carburetor icing.

c. Controlling the air-fuel mixture in injected gasoline engines - the problem.

(1) The problem of providing fuel to engine cylinders would be comparatively simple for gasoline engines if it were not for the changes in air-fuel ratio that are demanded. Figure 4-6 shows the air-fuel ratios required by the engine at various throttle and load conditions. Three conditions are apparent.

(a) Idling and low speed (A-B).

(b) Economy range, medium loads (B-C).

(c) Power range with full load (C-D).

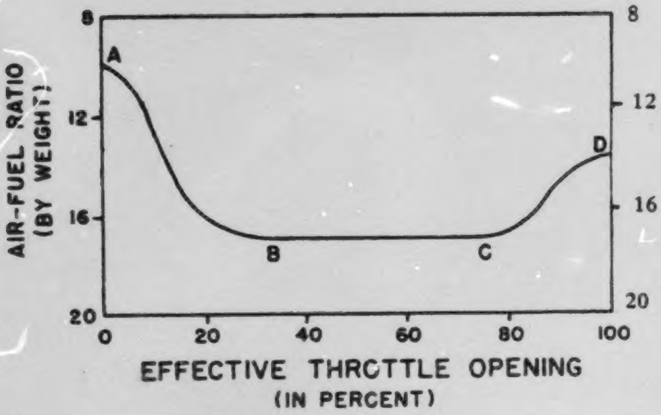


Figure 4-6. Air-fuel and fuel-air ratios required by the engines at various throttle positions.

(2) At idling speed the air-fuel mixture is diluted by a high percentage of inert exhaust gases; therefore, an excessively rich mixture to provide combustion must be supplied. As the throttle is opened past the idling or no-load position, the problem of exhaust gas dilution is minimized. At this point the engine operates in its maximum economy range; if the mixture is well vaporized and the manifold correctly designed, the ideal 16-17 to 1 air-fuel ratio can be approached. Due to the lean mixture in this economy zone the flame is slow in traveling through the combustion chamber. For this reason the spark must be advanced for maximum economy. Opening the throttle to approximately the three-quarter position in the power range requires a rich mixture for two reasons.

(a) Maximum power requirement is assumed; therefore, a rich mixture becomes necessary.

(b) Lean mixtures, such as in the economy range, cause a tendency toward valve failure.

The first reason is supported by information found elsewhere in this text which states that maximum power is attained when all the air is consumed. The second reason is apparent when it is realized that lean mixtures burn slowly and hence exhaust gases are hotter when they pass through exhaust valves. Also, at higher speed there is less time for the exhaust valves to cool.

d. **Controlling the air-fuel mixture in injected gasoline engines - solution to the problem.** There are several approaches for a solution to varying the air-fuel mixture in fuel injected systems. Three methods that will proportion both air and fuel are (1) throttle control of both air and fuel by mechanical linkage; (2) throttle control of air supply, causing automatic control of fuel; and (3) throttle control of fuel causing automatic control of air. Methods (1) and (2) are the ones employed in most military tracked vehicle engines and are the ones discussed.

(1) **Control by mechanical linkage.** In this method the accelerator is connected by linkage to the throttle valve in a way similar to that found in the carbureted system to control the air intake. The linkage is also connected to a metering device to mechanically meter the fuel in corresponding amounts to maintain the proper air-fuel ratio.

(2) Throttle air control and automatic fuel control. This system is employed in the Simmonds fuel injection systems used in engines. The air throttle is controlled by mechanical linkage. The fuel is metered by sensing the engine speed and intake air density and translating this into corresponding fuel discharge. The engine speed factor is imposed on the pump directly by the engine. Manifold pressure can be used as a measure of air density if compensation for temperature is made. As a reliable indicator of mass airflow at a constant temperature, manifold pressure is satisfactory over the entire speed range. Air density change due to variance in temperature, however, is quite significant. For example, to maintain a 12 to 1 air-fuel ratio of 0° F manifold temperature, an engine may pump 145 cubic feet of air. This same engine must induct 195 cubic feet of air to hold the same air-fuel ratio at 160° F. This additional air cannot be inducted since the engine is basically a constant volume pump, and as a result the air-fuel ratio is lowered. Obviously, some means of compensating for this variance must be provided. Fuel flow must be regulated to compensate for temperature changes. Errors in fuel flow can also be caused by barometric and altitude changes. Some systems compensate for these changes.

e. Advantages of fuel injection for gasoline engines. Many advantages are claimed for injected fuel systems, and a realization of these advantages depends on the type of system employed, the nature of the installation, and the type of operation the engine is used for. It is generally agreed that best results occur when the engine is designed with the intent of injecting in mind. Some of the more significant advantages are discussed in the following subparagraphs.

(1) Increased power. Increased power results because of increased volumetric efficiency due to two reasons:

(a) Intake manifolds can be simplified since their only function is to provide air for combustion. The manifolds can be made large because there is no need to maintain air velocity, such as is the case with the carburetor. Hence, the venturi restriction can be eliminated. The result is a free-flowing air intake allowing a maximum amount of dense air to enter the combustion chamber, dependent only on the engine demand. Maximum air availability assures maximum power output.

(b) Injection systems atomize the fuel mechanically; no manifold hot spot is required for vaporization. Elimination of the hot spot on the manifold allows cool dense air to enter the combustion chamber. Therefore, a larger amount of air-fuel mixture (by weight) can be packed into the combustion chamber. In the intake port injected engines the fuel is not vaporized until the piston comes up on the compression stroke. This also contributes to a denser air-fuel charge and a resulting increase in power.

(2) Torque increase at lower engine RPM. Carbureted engines that depend on intake air to meter and transport fuel cannot produce a condition in the combustion chamber conducive to high torque at low RPM. Injected engines can produce optimum airflow and fuel charge at a much lower RPM. Camshafts can then be designed to take advantage of this gain and produce higher torque in the lower RPM range. This is particularly advantageous to vehicles employing automatic transmissions.

(3) Increased economy.

(a) Injecting fuel with precise control of the amount and timing of fuel permits a leaner air-fuel mixture. There is much less deposited on the manifold wall, so the overall fuel required is less than that of the carburetor system.

(b) Distribution is more uniform among the cylinders. Heavy ends of fuel (the elements of fuel that are inert or have high vaporization points) resist vaporization and cannot be well distributed by an intake manifold. Therefore, the delivered fuel intake may differ among the cylinders. Injected systems distribute fuel in liquid form, assuring a homogeneous mixture in all cylinders. Injection of fuel at the intake valve port insures consumption of all the fuel metered, thus promoting economy.

(4) **Improved acceleration.** Acceleration is improved because the fuel is injected close to the combustion chamber. This eliminates the lag in acceleration due to the time required for fuel to pass through the manifold of a carbureted engine.

(5) **Icing problems minimized.** Occasionally, in carburetion, the formation of ice partially blocks the venturi. The icing results from the cooling effect of the expanding air after it leaves the venturi and the vaporization of fuel. When icing occurs, the intake air is restricted and the output capabilities of the engine are limited. Since the injection system does not have a venturi restriction, this icing problem does not occur.

(6) **Backfire is minimized.** In port injected systems the danger of backfire is reduced because there are no hot fuel vapors in the manifold.

(7) **Improved engine attitude.** There is much less change in fuel distribution due to changes in engine position in the injected system. Carburetors are quite sensitive to engine position due to changes in float bowl fuel level when the vehicle is on an incline.

f. **Disadvantages of fuel injection.** In a comparison of performance, there is no disadvantage of any consequence in fuel injected engines when they are compared with carbureted engines. However, several items of installation and maintenance may be considered disadvantages.

(1) Due to the nature of the mechanical working parts and their close tolerances, a finer degree of fuel filtration than that currently applied to the carburetor engine is necessary.

(2) In order that the fuel injector may meter fuel properly at high fuel temperatures, a higher fuel supply pressure to the injector is required than that currently applied to the carburetor system.

(3) The initial cost of the system may be greater, depending on which carburetor systems are considered.

(4) There are more moving parts in the injector system which may contribute somewhat to a higher maintenance cost. Adjustment and calibration of injector systems require skilled personnel and complex equipment.

SECTION V. SIMMONDS FUEL INJECTION SYSTEM, DESCRIPTION AND PRINCIPLES OF OPERATION

5-1. GENERAL. The Simmonds SU fuel injection system has been adopted by the Army for use on some engines. The model used on each engine may differ. Table 5-1 gives the engine model and type of Simmonds pump employed on each production model. As indicated in table 5-1, future engine requirements will be met with injected engines. Figures 5-1 and 5-2 illustrate production model engines employed in tracked vehicles which utilize fuel injection. All Simmonds SU injection systems are similar in operation and construction principles. However, their installation on engines varies as to the type of auxiliary controls used.

Table 5-1. Simmonds Fuel Injector Pump Assemblies in Ordnance Number Sequence.

Ordnance part No	Federal stock No	Simmonds part No	Model No	Simmonds type	Engine application Continental model No	Continental part No
7973713	2910-333-5006	570057	SU-15G3	SU-15	AVI 1790-8	551963
7974093	2910-571-6981	570060	SU-15C5	SU-15	AVSI 1790-6	552049
7974355	2910-695-2962	570062	SU-15D7	SU-15	AOSI 895-5	552082
8735882	2910-571-6766	570214	SU-570	SU-570	AOI 402-5	528959
8725160	2910-678-7100	570080	SU-570	SU-570	AVI 1790-8	553962
7017523		570099	SU-570	SU-570	AOSI 895-5	553739
10865193	2910-714-8653	572000	SU-570	SU-570	AVSI 1790-6A	554250
570057	2910-333-5006	7973713	SU-15G3	SU-15	AVI 1790-8	551963
570060	2910-571-6981	7974093	SU-15C5	SU-15	AVSI 1790-6	552049
570062	2910-695-2962	7974355	SU-15D7	SU-15	AOSI 895-5	552082
570214	2910-571-6766	8735882	SU-570	SU-570	AOI 402-5	551963
570080	2910-678-7100	8725160	SU-570	SU-570	AVI 1790-8	553982
570099		7017523	SU-570	SU-570	AOSI 895-5	553739
572000	2910-714-8653	10865193	SU-570	SU-570	AVSI 1790-6A	554250

5-2. DATA. Table 5-2 provides the general data applicable to a typical SU fuel system employing the SU series injector pump (fig 5-3 thru 5-6).

Table 5-2. General Data, Typical SU Fuel System.

Overall length	8.87 in
Diameter at mounting end	Approx 4 in
Maximum height from centerline at solenoid end of injection pump	4.62 in
Maximum fuel delivery (lb per revolution)	0.00369
Minimum engine oil pressure	30 PSI
Minimum fuel pressure	15 PSI
Injection pump mounting	Mounting pad and 3 studs, 5/16-in diameter
Mounting drive ratio (to crankshaft)	1:1
Weight of pump	Approx 8 lb
Injector nozzle mounting	Bosses on intake manifold
Weight of injector nozzle	Approx 3 oz

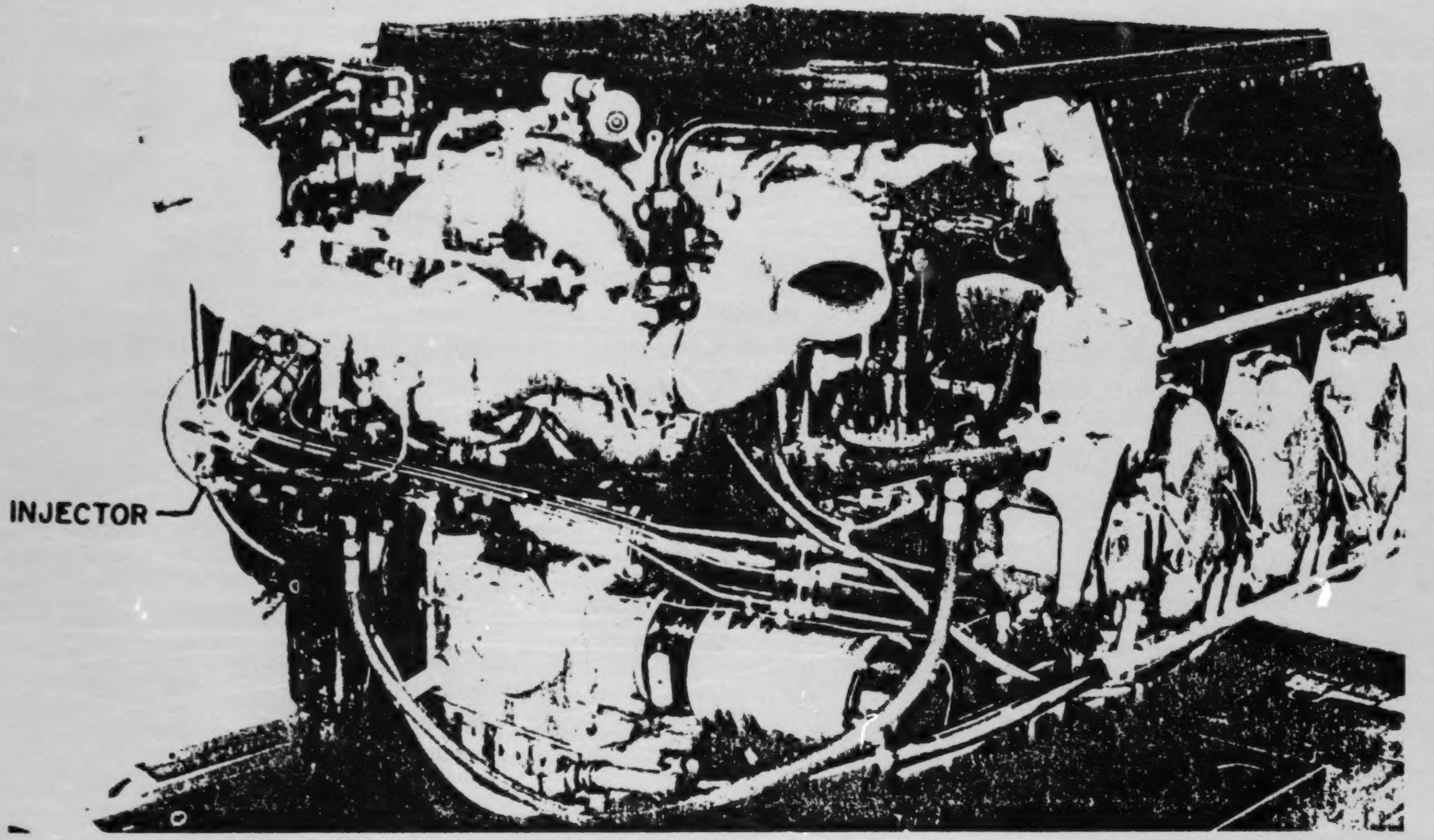


Figure 5-1. AOSI 895-3 engine (used in gun, twin 40mm, self-propelled M42A1).

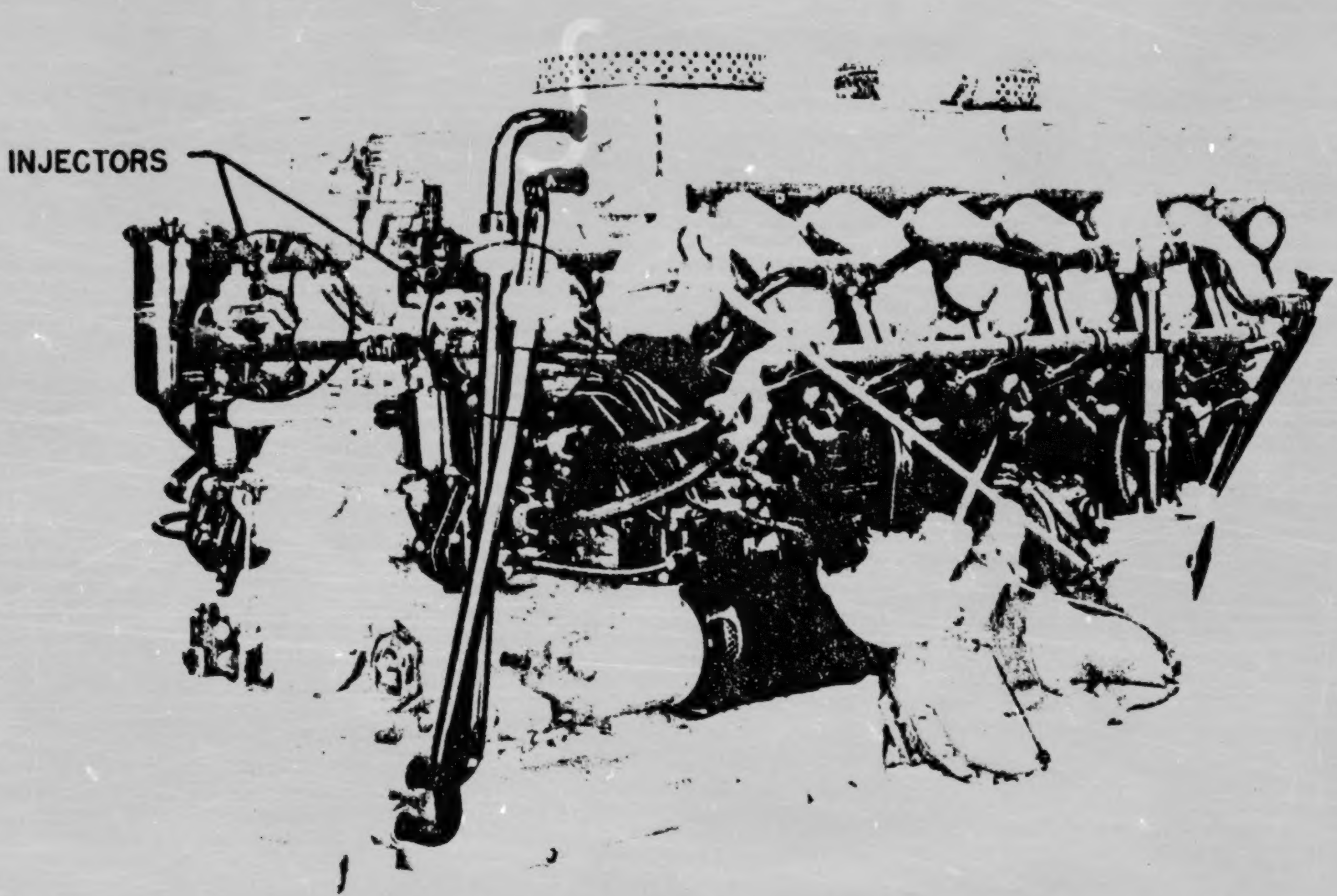
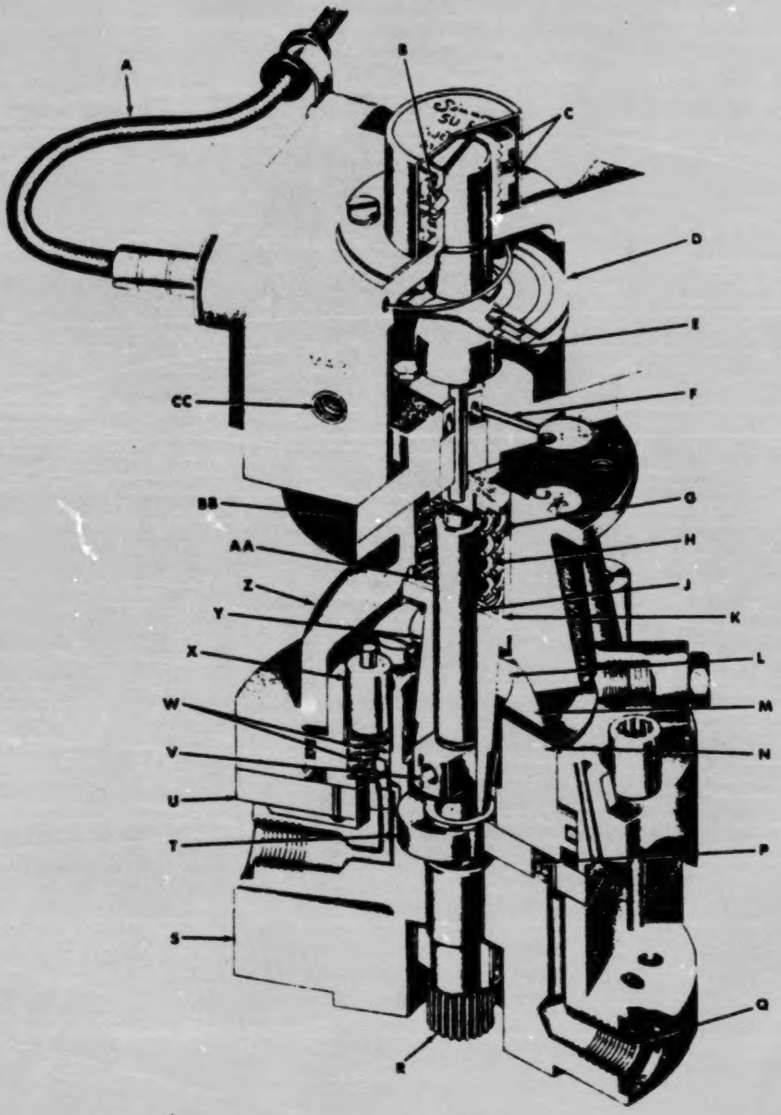
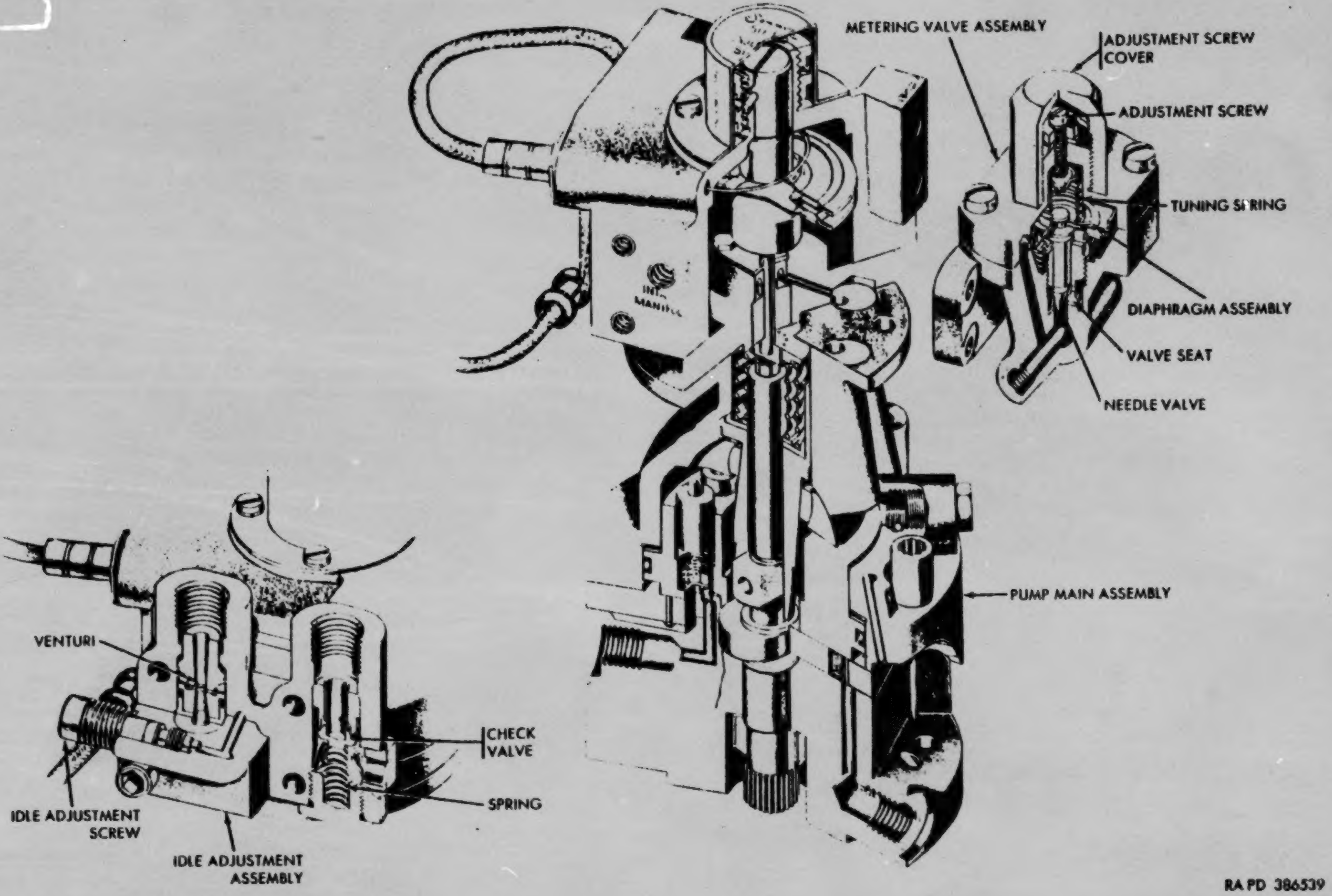


Figure 5-2. AVSI 1790 engine (used in tank recovery vehicle M88).



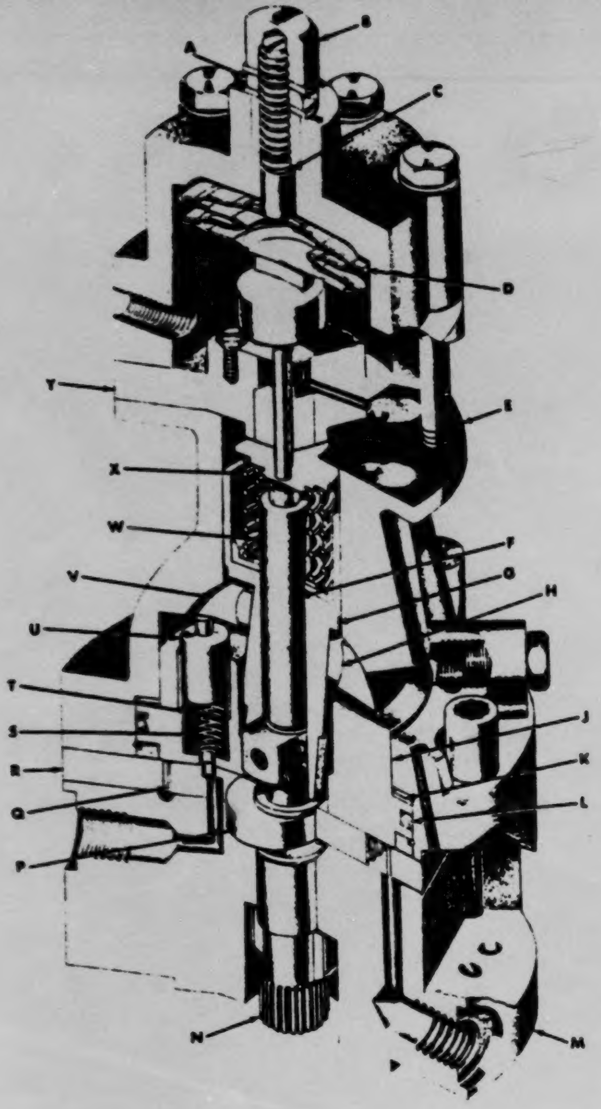
A–Capillary tube assembly
B–Capsule cross-pin
C–Capsule adjustment nuts
D–Capsule assembly
E–Oil valve spring plate, and shaft assembly
F–Oil drain hole
G–Outer tuning spring
H–Inner tuning spring
J–Mainshaft assembly
K–Tuning spring retaining plate
L–Wobble plate ball
M–Wobble plate
N–Plunger block assembly
P–Distributor valve
Q–Fuel port
R–Splined end of mainshaft assembly
S–Distributor block assembly
T–Mainshaft eccentric
U–Ring gear assembly
V–Mainshaft cross-piece oil hole
W–Inner and outer plunger springs
X–Plunger assembly
Y–Skew shaft
Z–Main body
AA–Inner tuning spring shim
BB–Sandwich piece assembly
CC–Manifold pressure port

Figure 5-3. Fuel injector pump assembly 7973713—cross-sectional view.


METERING VALVE ASSEMBLY
ADJUSTMENT SCREW COVER
ADJUSTMENT SCREW
TUNING SPRING
DIAPHRAGM ASSEMBLY
VALVE SEAT
NEEDLE VALVE
PUMP MAIN ASSEMBLY
VENTURI
CHECK VALVE
SPRING
IDLE ADJUSTMENT SCREW
IDLE ADJUSTMENT ASSEMBLY

RA PD 386539

Figure 5-4. Fuel injector pump assemblies 7974093 and 7974355—cross-sectional view.



A–Check nut
B–Capnut
C–Capsule "O" ring preformed packing
D–Capsule assembly
E–Sandwich piece gasket
F–Mainshaft assembly
G–Skew shaft
H–Wobble plate ball
J–Plunger block assembly
K–Plunger block thrust washer
L–Plunger block thrust seal
M–Distributor block assembly

N–Splined end of mainshaft
P–Mainshaft eccentric
Q–Distributor valve
R–Ring gear assembly
S–Inner plunger spring
T–Outer plunger spring
U–Plunger assembly
V–Wobble plate
W–Inner tuning spring
X–Outer tuning spring
Y–Sandwich piece assembly

Figure 5-5. Fuel injector pump assembly 8735882—cross-sectional view.

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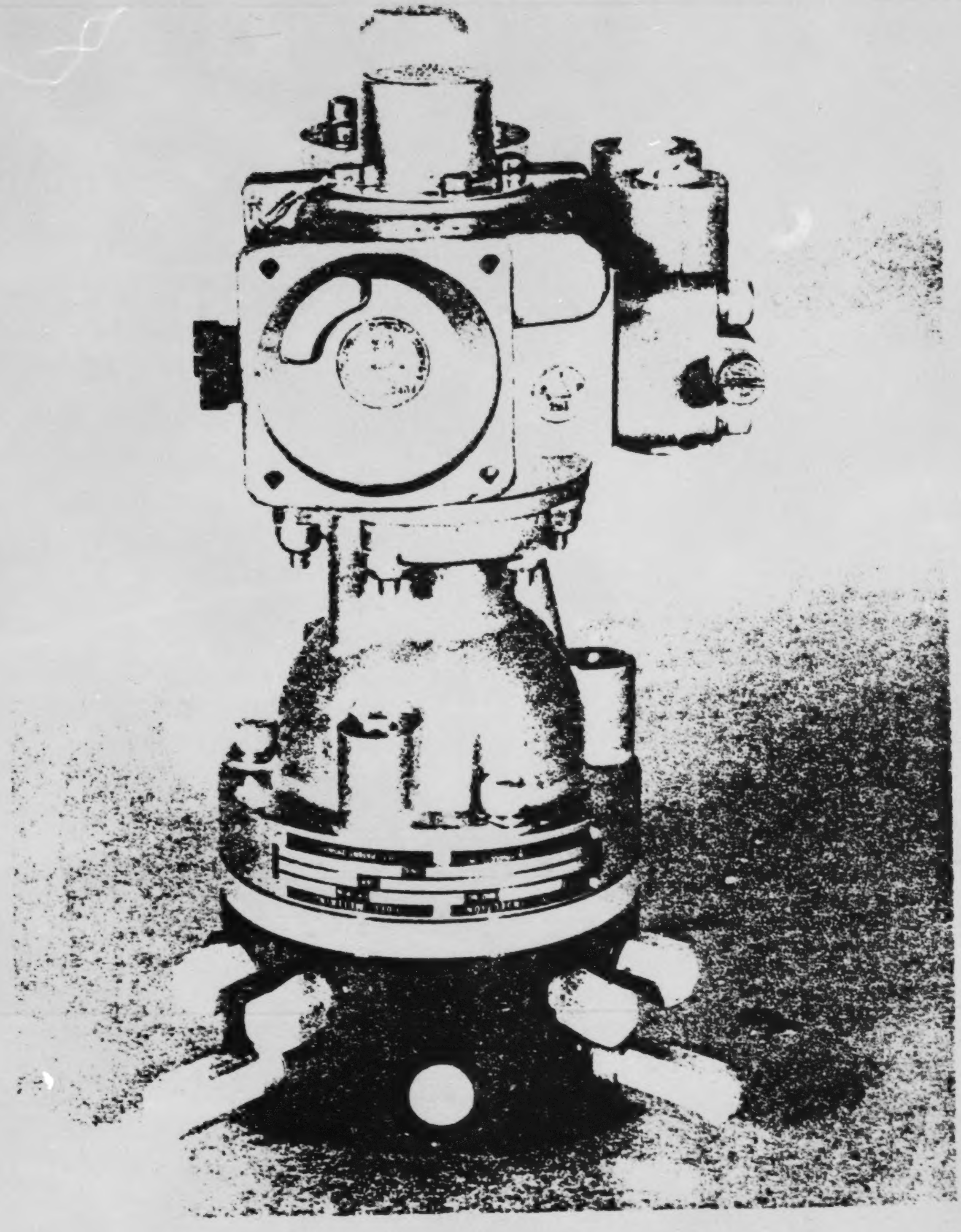

Figure 5-6. Simmonds fuel injector pump.

5-3. GENERAL DESCRIPTION. The injector pump is comprised of these major parts or subassemblies: the capsule housing assembly, the sandwich piece assembly, tuning springs, pump body, skew shaft, main shaft, wobble plate and ball, plunger block assembly, ring gear, distributor valve, distributor block, and the injector nozzles. See figures 5-7 through 5-21.

a. **Capsule housing assembly.** Enclosed and supported by the capsule housing is the capsule assembly and, if used, the temperature sensing bulb, the idle control device, and the fuel metering control valve. A threaded shoulder with two adjusting nuts provides for vernier adjustment of the capsule.

b. **Sandwich piece assembly.** Included in the sandwich piece assembly is the central bore that supports the servovalve shaft and an oil restrictor leading to the oil drain passage.

c. **Tuning springs.** There are two tuning springs. The outer one bears against the servovalve and the servo of the skew shaft. The inner smaller spring is retained to a shoulder on the servovalve. The tuning springs regulate the position of the servovalve and skew shaft in response to force differential in the servosystem.

d. **Pump body.** Included in the pump body are a bore for the skew shaft, a spherical socket in which the wobble plate oscillates, and oil inlet and outlet passages.

e. **Skew shaft.** Located on one end of the skew shaft is the servopiston. The other end of the skew shaft is set at an angle (skewed) and passes through the ball ring. On the skewed end there is a slot that engages a lobe on the main shaft, permitting the skew shaft to be driven by the main shaft. The angular position of the wobble plate is dependent on the axial movement of the skew shaft. Pressure differential across the skew shaft and tuning springs produces the axial movement.

f. **Main shaft.** The main shaft is driven by the engine through a splined coupling. A lobe on one end engages and drives the skew shaft. On the other end there is a cam that actuates the fuel distribution valve. A drilled passage through the lobe and center of the main shaft permits passage of oil to the servochamber.

g. **Wobble plate and ball.** The wobble plate is mounted on the ball and seats in the spherical socket provided in the pump housing. Rotation of the skew shaft causes the wobble plate to oscillate, thereby actuating the pump plungers. The position of the ball ring on the skewed portion of the skew shaft determines the length of the plunger stroke and the quantity of fuel output.

h. **Plunger block assembly.** Included in the plunger block assembly are the plunger block, plungers and plunger springs, O-ring, and the wave spring. Movement of the plungers is caused by the oscillation of the wobble plate, while the length of the stroke is regulated by the position of the wobble plate on the skewed portion of the skew shaft. The fuel pump forces fuel into the respective plunger bores and is injected in a timed sequence.

i. **Ring gear and valve.** The ring gear is sandwiched between the pump body and distributor block and remains stationary. Internal gear teeth of the ring gear mesh with the teeth of the valve gear. The valve serves to distribute the fuel to the proper ports. The valve has ports that aline with the ports in the distributor block and the plunger block assembly, permitting the intake and ejection of fuel in properly timed sequence when rotated by the main shaft cam.

j. **Distributor block.** The distributor block has a support bearing for the main shaft and drilled passages for the fuel supply, fuel venting, fuel discharge, and oil supply and drain.

A–Capsule assembly
B–Oil valve and shaft assembly
C–Outer tuning spring
D–Inner tuning spring
E–Skew shaft servopiston
F–Skew shaft
G–Alternate supply oil inlet
H–Plunger assembly
J–Plunger bore
K–Plunger block
L–Distributor valve
M–Main shaft eccentric
N–Distributor block
P–Fuel inlet
Q–Supply oil inlet
R–Drain oil outlet
S–Fuel outlet (to nozzle)
T–Ring gear assembly
U–Distributor valve port
V–Main shaft oil inlet
W–Wobble plate
X–Wobble plate ball
Y–Main shaft assembly
Z–Main shaft oil outlet
AA–Sandwich piece assembly
BB–Drain oil orifice
CC–Manifold pressure connection

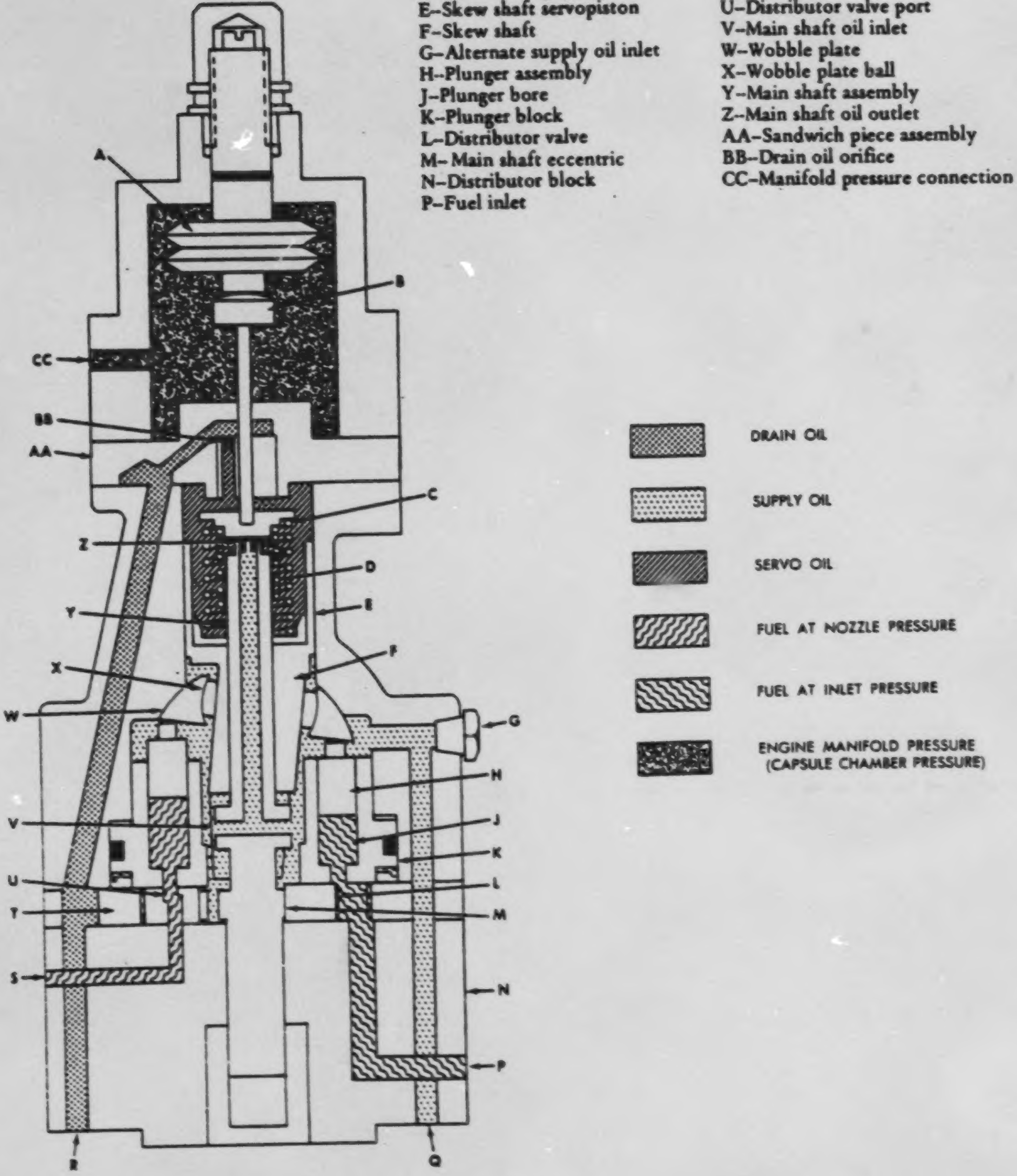
A
B
CC
BB
AA
C
Z
D
E
Y
F
X
W
G
H
V
J
K
U
L
T
M
S
N
P
R
Q
DRAIN OIL
SUPPLY OIL
SERVO OIL
FUEL AT NOZZLE PRESSURE
FUEL AT INLET PRESSURE
ENGINE MANIFOLD PRESSURE (CAPSULE CHAMBER PRESSURE)

Figure 5-7. Fuel injector pump assembly 8735882—functional diagram.

k. Injector nozzles. The nozzle is comprised of the valve, spring, filter screen, and the injector retainer. The number of cylinders determines the number of nozzles required.

5-4. CONSTRUCTION OF COMPONENTS.

a. Capsule housing assembly (fig 5-8 thru 5-10).

(1) The aluminum housing contains the capsule assembly. When used, the temperature bulb and capillary tube are permanently affixed to the capsule and are considered as part of the assembly. The housing has a threaded boss that mounts the two capsule adjusting nuts. Studs are provided on the circular flanged face for mounting the capsule housing on the sandwich piece and main body.

A—CAPSULE ASSY.—7043937
B—CAPSULE "O" RING PREFORMED PACKING—96906-MS29513-12
C—⅛-IN. HEX-HD PIPE PLUG—88044-AN932-1
D—BOTTOM CAPSULE ADJUSTMENT NUT—8389862
E—CAPSULE CROSS-PIN—77932-570134
F—TOP CAPSULE ADJUSTMENT NUT—8389863
G—METERING HD HOUSING W STUDS—77932-570752
H—LOCKING WIRE—0.032 DIA SF
J—NO. 10 INT-TEETH LOCK WASHER—88044-AN936-A10
K—CAPILLARY TUBE CLAMP—96906-MS21919F4
L—NO. 10 SCREW—88044-AN148555
M—CAPILLARY TUBE ASSY W TEMPERATURE BULB ASSY—NO NUMBER

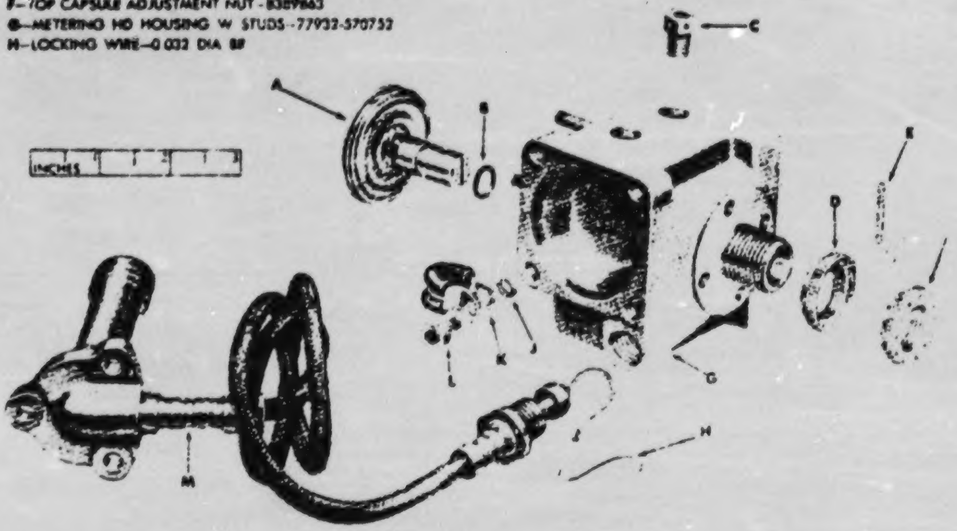

Figure 5-8. Original metering head assembly—exploded view.

(2) The capsule assembly is housed in the aluminum casting with the stalk of the capsule passing through the central bore of the threaded boss (fig 5-9). An adjusting pin passes through the capsule stalk and threaded boss at right angles to their axes. The adjusting pin is nested between the two adjusting nuts. Movement of the adjusting nuts causes axial movement of the adjusting pin and capsule stalk (the adjusting pinhole in the threaded boss is elongated to permit axial motion). This movement changes the fuel output of the injector pump.

(3) Six studs protruding from the capsule bore opening side of the housing serve to attach the sandwich piece and capsule housing to the pump body.

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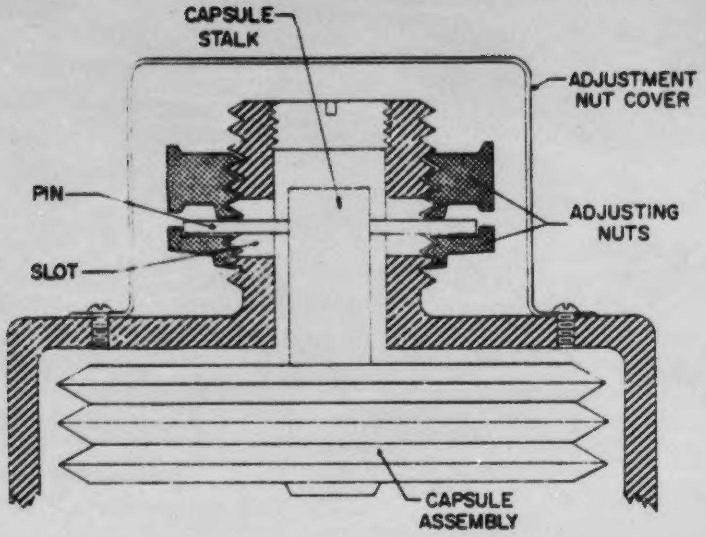
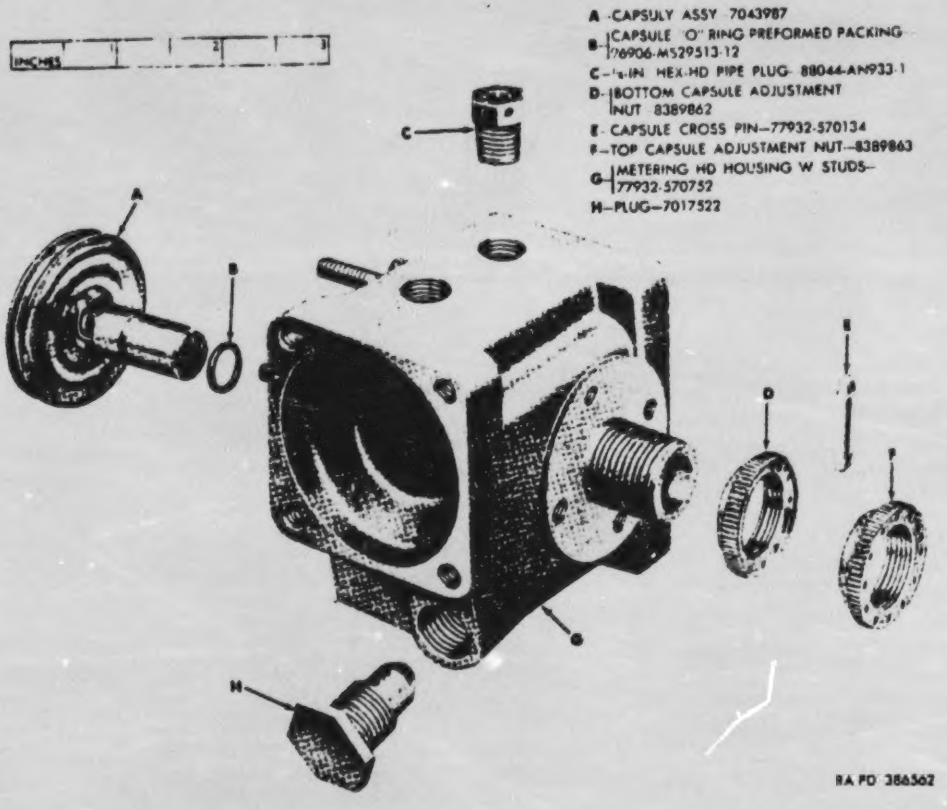

CAPSULE STALK
ADJUSTMENT NUT COVER
PIN
ADJUSTING NUTS
SLOT
CAPSULE ASSEMBLY

Figure 5-9. Capsule housing assembly—cross section.


INCHES
1
2
3
A -CAPSULY ASSY 7043987
B-CAPSULE "O" RING PREFORMED PACKING- 76906-MS29513-12
C-⅛-IN HEX-HD PIPE PLUG- 88044-AN933-1
D-BOTTOM CAPSULE ADJUSTMENT NUT 8389862
E-CAPSULE CROSS PIN—77932-570134
F—TOP CAPSULE ADJUSTMENT NUT—8389863
G-METERING HD HOUSING W STUDS—77932-570752
H—PLUG—7017522
A
B
C
D
E
F
G
H

RA PD 386562

Figure 5-10. Converted metering head assembly (capillary tube and temperature bulb removed)—exploded view.

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(4) Provision for mounting two manifold pressure sensing tubes is made with two threaded port bosses on the side of the housing. The capillary tube of the temperature bulb is attached to an adjacent boss. Since the capillary tube is permanently affixed to the capsule housing assembly, it should not be tampered with. The capillary tube and sensing bulb are not used on new engine applications or rebuilt pumps because it has been discovered that manifold heat changes affect the capsule without using the heat sensing bulb.

b. Sandwich piece assembly (fig 5-11).

(1) The sandwich piece is a machined aluminum disk with a boss on one side. A central bore through the boss supports the servovalve shaft while a counterbore receives the servovalve shaft oil seal. An oil restrictor passage extends at an angle from the central part of the sandwich piece to be joined to the oil drain passage of the main pump body by a drilled passage and a counterbore.

(2) A tapered cone on one end of the servovalve shaft seats in a miniature bearing pressed into an outer race. The bearing is permanently lubricated by grease placed in a soft copper cup before it is permanently attached to the outer race of the bearing. On the other end, the servovalve shaft is pressed into the servovalve seat. The brass bushing in the central bore is drilled to permit oil to drain into drilled passages from the valve seat restrictor passage. A brass plate across the top of the sandwich piece boss retains the oil seal.

(3) Six equally spaced drilled holes around the outer periphery receive the studs of the capsule housing and serve to fasten the sandwich piece to the main pump body. The seventh hole is a continuation of the accelerator pump oil passage.

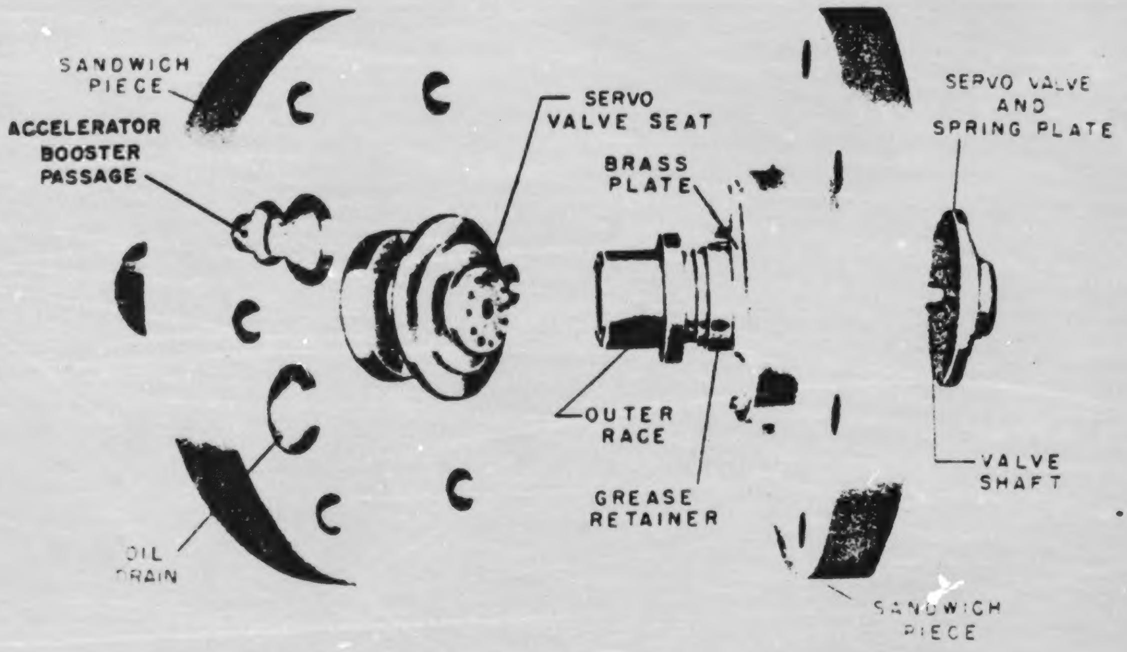

Figure 5-11. Sandwich piece assembly.

c. **Tuning springs** (fig 5-12). The inner and outer tuning springs are made of music wire. The tuning springs provide the force differential to position the skew shaft and wobble plate when the oil pressures on both sides of the servo are balanced. It is in this manner that the fuel is metered to meet manifold pressure and temperature changes.

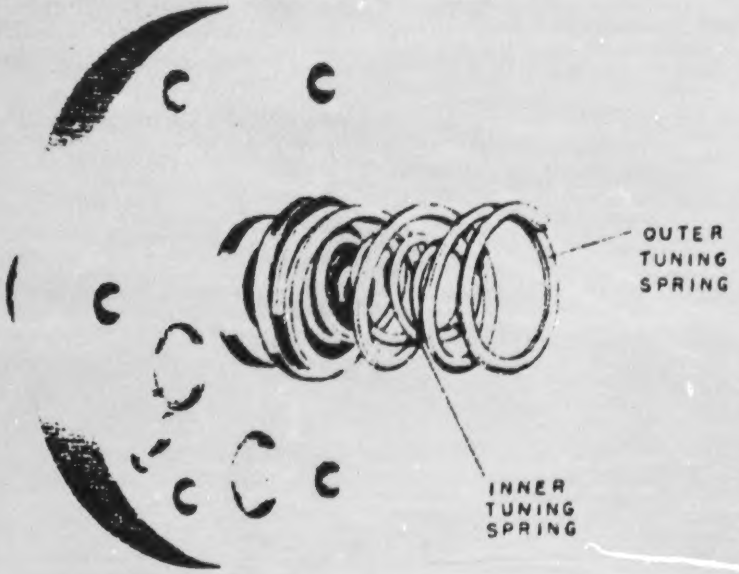
OUTER TUNING SPRING
INNER TUNING SPRING

Figure 5-12. Tuning springs.

d. Pump body (fig 5-13).

(1) The one-piece aluminum casting pump body contains the following: central bored hole, drilled oil drain passage, threaded oil supply port, spherical surface with three equally spaced slots extending radially from the central bore, and a stepped counterbore with a locating slot to receive the dowel pin of the plunger block assembly.

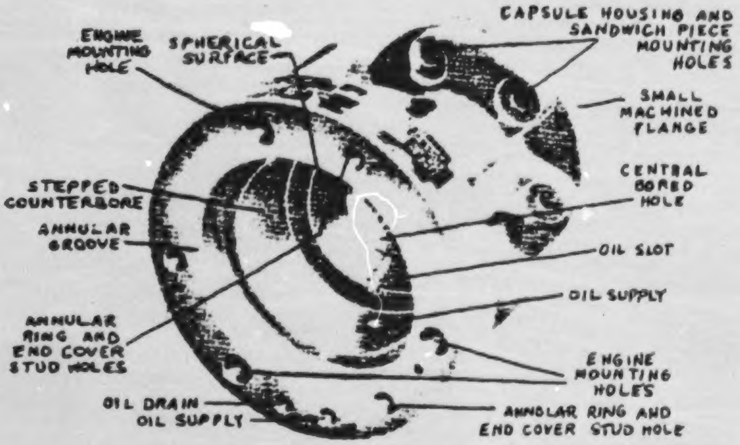
ENGINE MOUNTING HOLE
SPHERICAL SURFACE
CAPSULE HOUSING AND SANDWICH PIECE MOUNTING HOLES
SMALL MACHINED FLANGE
CENTRAL BORED HOLE
STEPPED COUNTERBORE
ANNULAR GROOVE
OIL SLOT
OIL SUPPLY
ANNULAR RING AND END COVER STUD HOLES
ENGINE MOUNTING HOLES
OIL DRAIN
OIL SUPPLY
ANNULAR RING AND END COVER STUD HOLE

Figure 5-13. Pump body.

(2) The central bore receives the servo of the skew shaft and serves as a servo chamber. The spherical surface at the one end of the central bore will position the wobble plate that is mounted on the skew shaft by a ball ring. The angular position of the wobble plate is varied by the axial motion of the skew shaft in its bore and determines the quantity of fuel displaced by the plungers. Rotary motion of the wobble plate, due to rotation of the skew shaft, actuates the plungers which receive and eject the metered fuel to the various cylinder nozzles.

(3) The stepped bore provides a seat for the plunger block assembly and a locating slot receives the dowel on the plunger block.

(4) The smaller round flange has six stud holes on the mounting face to receive the studs that mount the sandwich piece and capsule housing assembly. The three holes in the larger flange that have raised bosses admit the studs of the engine mounting pad. The hole drilled lengthwise through the pump body connects the oil drain passage of the capsule housing with a similar passage in the distributor block. A 1/8-inch pipe thread port is provided for use when supply of engine oil pressure is made externally.

e. **Skew shaft.** The skew shaft (fig 5-14) is a machined meehanite casting. When placed in position, the end with the servo fits into the central bore of the pump body and retains the tuning springs. A forked end on the skewed portion of the shaft engages and is driven by the lobe on the main shaft. A central bore permits the skew shaft to slide axially over the main shaft. Differences in oil pressure on either side of the servo and the force of the tuning springs will cause axial motion of the skew shaft. The angular position of the wobble plate is determined by its position on the skewed portion of the skew shaft.

Note. - Meehanite is a high grade of cast iron with excellent wear resistance and self-lubricating properties.

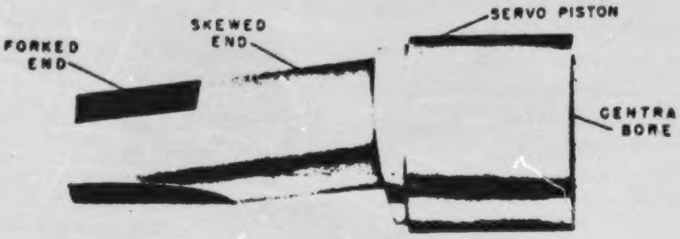

Figure 5-14. Skew shaft.

f. **Main shaft.** The main shaft (fig 5-15) is a steel rod with a splined end coupled to the engine accessory drive. The shaft has a lobe for driving the skew shaft and an eccentric cam to actuate the fuel distribution valve. A hole drilled transverse to the axis of the shaft and extending through the lobe to a central bore provides an oil passage to the upper servochamber. The central bore terminates at the servovalve seat.

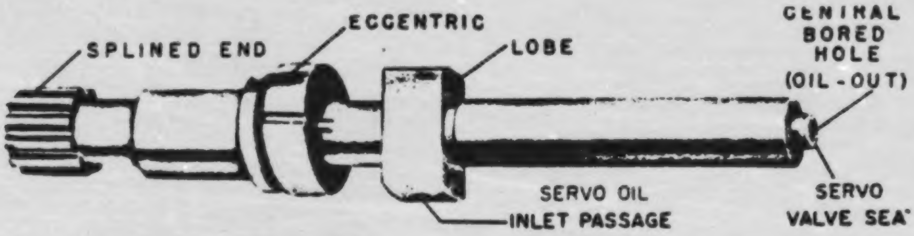

Figure 5-15. Main shaft.

g. **Wobble plate and ball.** The ball and wobble plate (fig 5-16) are hardened, machined steel parts. The wobble plate seats in the spherical socket of the pump body. The ball serves as a flexible joint, allowing the wobble plate to oscillate when driven by the skewed portion of the skew shaft. The radial and axial movement of the periphery of the wobble plate causes the plungers to receive and eject fuel in the proper sequence.

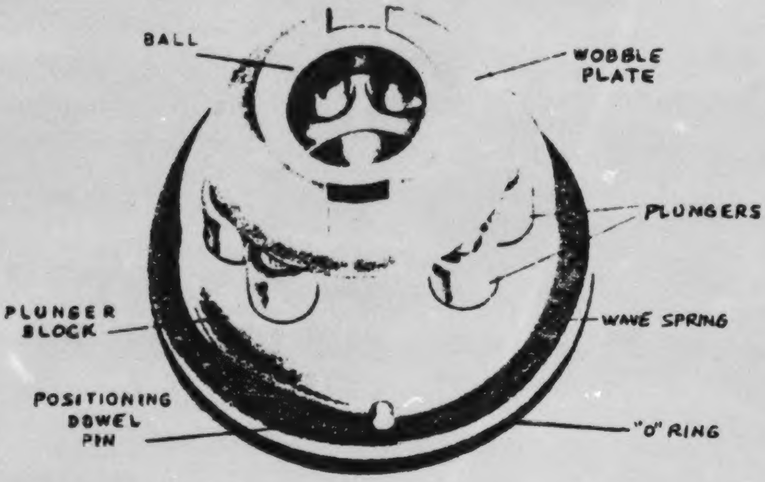
BALL
WOBBLE PLATE
PLUNGERS
PLUNGER BLOCK
WAVE SPRING
POSITIONING DOWEL PIN
"O" RING

Figure 5-16. Wobble plate, ball, and plunger block assembly.

h. **Plunger block assembly.** The plunger block (fig 5-17) is a machined aluminum or meehanite cylinder that has a central bore and equally spaced plunger bores. The plungers, made of chromium plated brass, are interchangeable. The skew shaft and the main shaft pass through the central bore. The springs in the plunger bores load the plungers against the wobble plate and, as previously explained, the plungers are actuated by the wobble plate. A wave spring loads the plunger block assembly against the valve gear to form a seal. The C-ring, on the outer periphery of the plunger block, is a seal to prevent the oil from leaking into the fuel. The plunger block assembly seats in the stepped bore of the pump body where it is positioned by a locating dowel and retained by a large circlip.

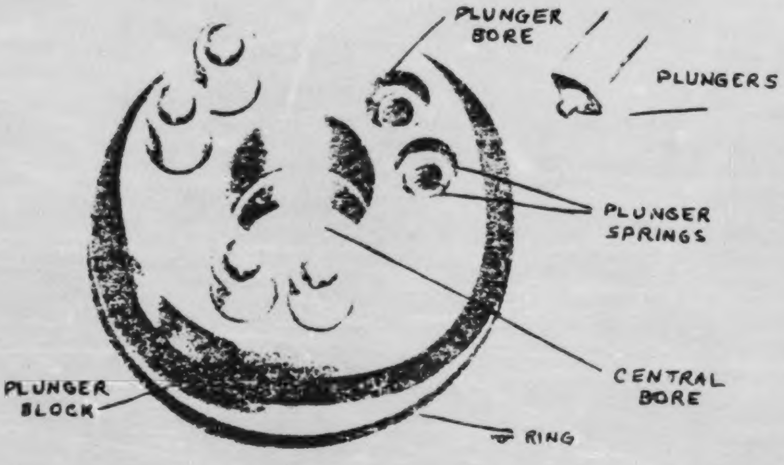
PLUNGER BORE
PLUNGERS
PLUNGER SPRINGS
CENTRAL BORE
PLUNGER BLOCK
RING

Figure 5-17. Plunger block assembly.

i. Ring gear and valve.

(1) The annular ring (fig 5-18) is an internal toothed, annular ring gear held in a fixed position between the end cover and the pump body by three studs. The internal teeth mesh with the external teeth of the distributor valve. Drilled holes allow continuation of the oil supply and drain passages in the pump body and distributor block.

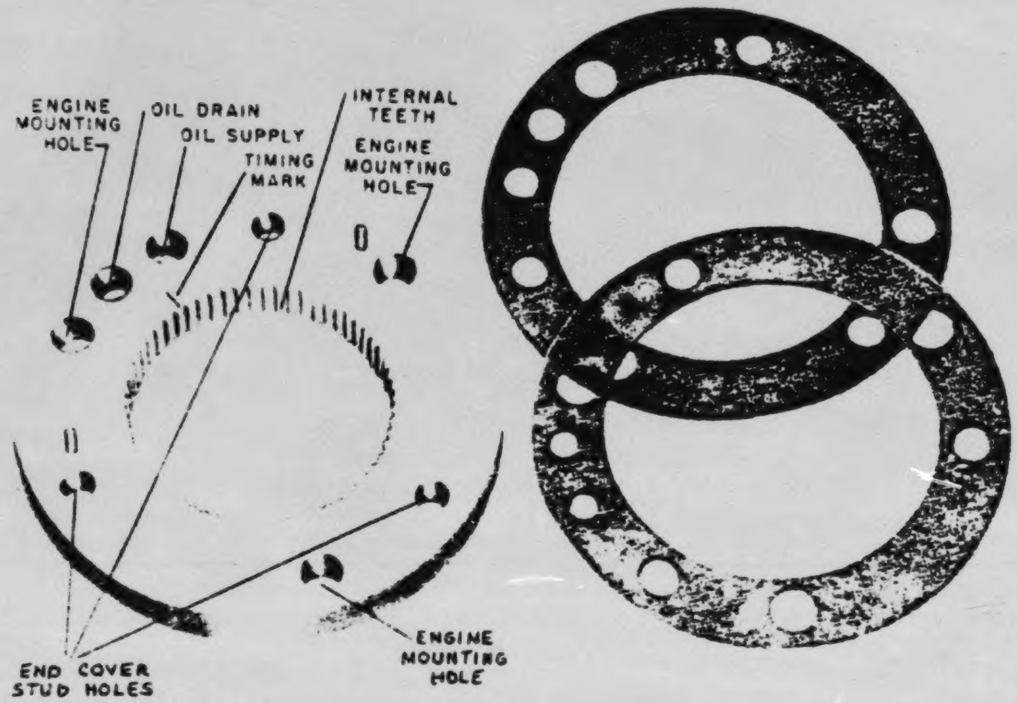

Figure 5-18. Ring gear and gaskets.

(2) The valve (fig 5-19) is a machined meehanite casting, resembling a gear, with eight kidney-shaped ports equally spaced that meet with eight drilled holes coming through from the other side. The kidney-shaped ports and drilled holes deliver fuel from the plunger bores to the distributor block passages in proper sequence. The external teeth of the valve mesh with the teeth of the ring gear. The central bore fits over the eccentric of the main shaft. Pressure from the wave spring sandwiches the valve between the plunger block and distributor block. A timing mark on the valve is to be alined with a similar mark on the ring gear to secure the correct relationship between the wobble plate throw and the position of the main shaft eccentric.

(3) Revolving the main shaft eccentric in one direction will cause the valve to rotate in the opposite direction. The ratio between the valve and ring gear is 8 to 1. Hence, one revolution of the main shaft will result in one-eighth of a revolution of the valve. Fuel intake into the plunger bore is controlled by the edge of the valve. The action of the valve is timed with the stroke of the plunger so that the inlet opening to the plunger bore is uncovered when the plunger is on the intake stroke. After completion of the intake stroke, the valve moves to aline the kidney-shaped port and drilled hole with the discharge port of the distributor block. Each plunger will deliver fuel through each of the kidney-shaped ports in turn.

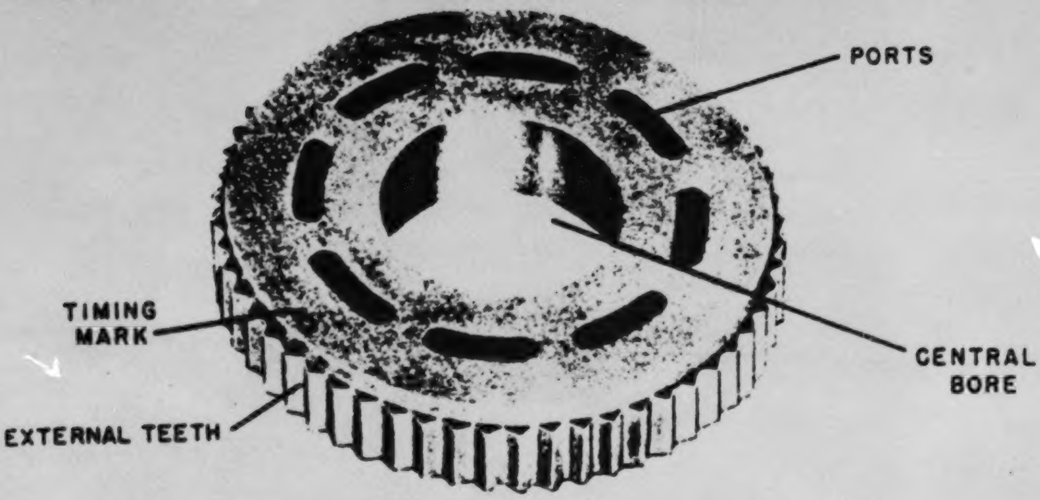

Figure 5-19. Distributor valve.

j. **Distributor block.**

(1) A cylindrical, machined, meehanite block forms the distributor block (fig 5-20) for the pump. It is comprised of the following components: oil inlet and outlet passages, fuel vent port, two alternate fuel inlet ports, and a central bore to support the main shaft bearing. Three studs located on the machined surface mount the distributor block to the pump body. Three holes passing through the casting permit mounting the entire pump to the engine. The arrow stamped on the distributor block indicates the direction of main shaft rotation.

(2) A 1/8-inch pipe-threaded brass fitting retains a fixed restrictor and vents fuel and vapor back to the fuel tank. The six outlet fuel fittings are lettered alphabetically to indicate the sequence of discharge. Two 1/4-inch threaded ports permit fuel to be supplied from either side of the pump. The two inlet drilled passages and the vent port are interconnected by the annular groove on the machined face of the distributor block.

(3) The six passages on the machined face are connected to the lettered discharge ports; each passage receives fuel from a plunger, and delivers it to the nozzle.

(4) The main shaft passes through the central bore and is retained by a split sleeve held together by a clip. Main shaft end play is controlled by shims placed between a thrust collar and the counterbore seat. Oil supply and oil drain passages on the engine mounting face mate with similar passages on the engine accessory mounting pad.

k. **Injector nozzles.** An injector nozzle (fig 5-21) is mounted on a boss on the intake manifold tube for each cylinder. The position of the valve is such that fuel sprays through the open intake valve port and into the combustion chamber as the air charge enters. The nozzles incorporate a filter screen and a pintle valve which is spring loaded to prevent leaking. Fuel pressure of 50 to 70 PSI is required to open the valve. The hemispherical shape of the valve and its seat promote better seating as the valve wears. This design also helps to make the nozzle self-cleaning, since dirt particles are forced from the seat by accelerating the engine just long enough to force an increased amount of gasoline through the nozzle.

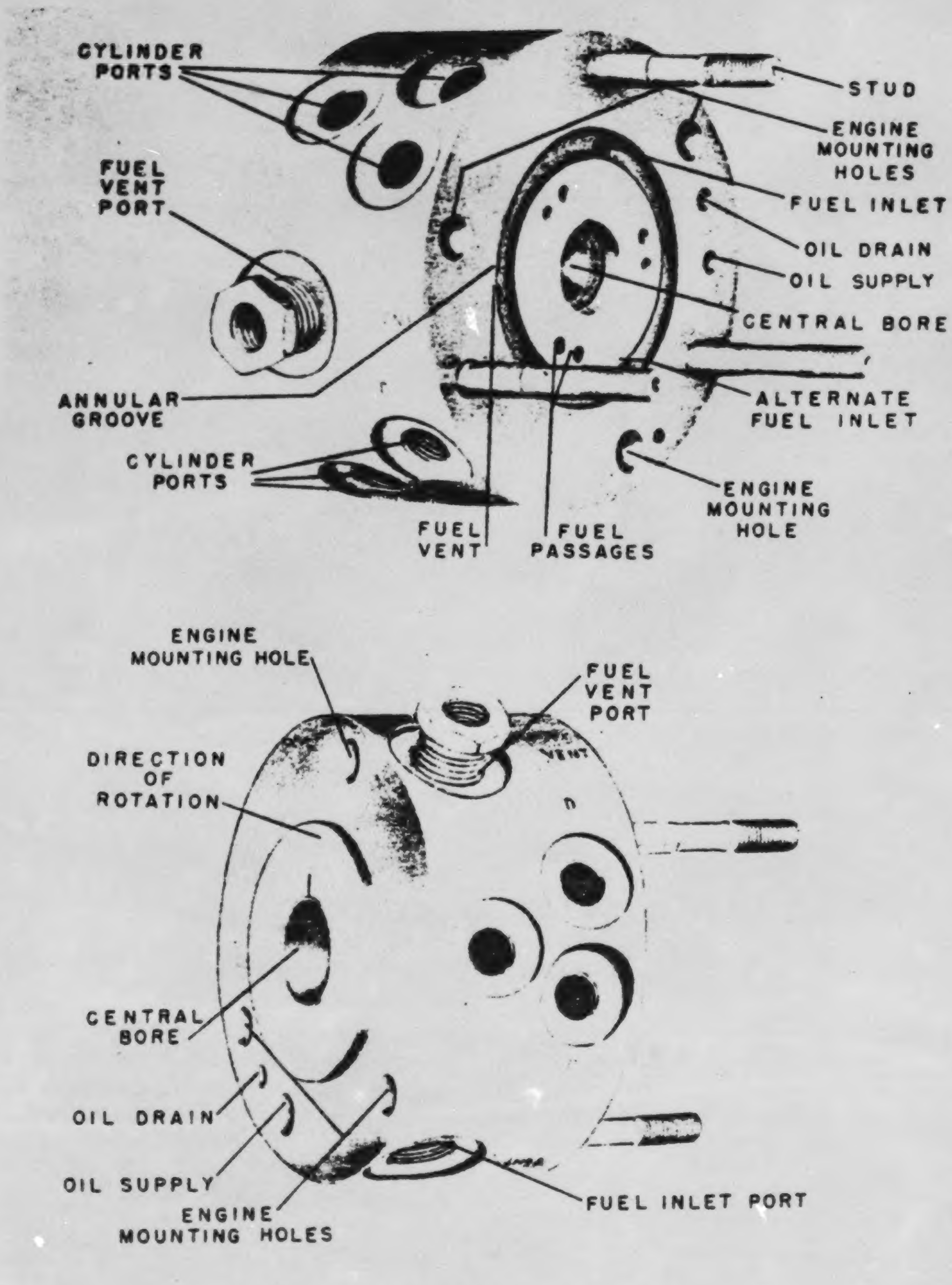
CYLINDER PORTS
STUD
ENGINE MOUNTING HOLES
FUEL VENT PORT
FUEL INLET
OIL DRAIN
OIL SUPPLY
CENTRAL BORE
ANNULAR GROOVE
ALTERNATE FUEL INLET
CYLINDER PORTS
ENGINE MOUNTING HOLE
FUEL VENT
FUEL PASSAGES
ENGINE MOUNTING HOLE
FUEL VENT PORT
VENT
DIRECTION OF ROTATION
CENTRAL BORE
OIL DRAIN
OIL SUPPLY
ENGINE MOUNTING HOLES
FUEL INLET PORT

Figure 5-20. Distributor block.

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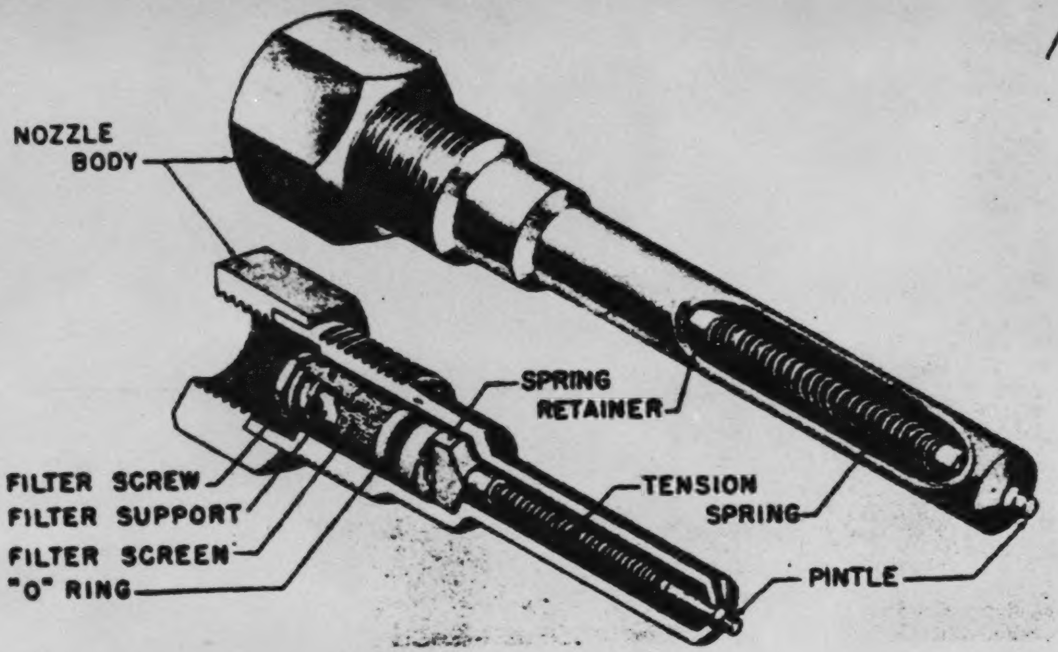

NOZZLE BODY
SPRING RETAINER
FILTER SCREW
FILTER SUPPORT
FILTER SCREEN
"O" RING
TENSION SPRING
PINTLE

Figure 5-21. Typical injector nozzles.

l. Differences between models.

(1) Differences between plunger block assemblies.

(a) The plunger block assembly originally used in fuel injector pump assemblies 7973713, 7974093, and 7974355 has six plunger bores arranged in three pairs. Six plungers are used, one in each bore, and they are spring loaded by one inner and one outer plunger spring in each bore. Plungers are positioned in the bore, threaded end first. Replacement plunger block assemblies are described in c below.

(b) The difference in the plunger block assembly used in fuel injector pump assembly 8735882 is that it has three plunger bores, plungers, and inner and outer springs for each bore (fig 5-22).

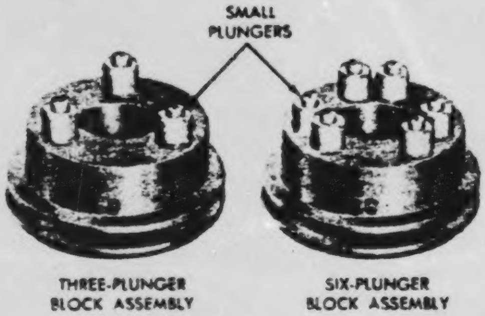
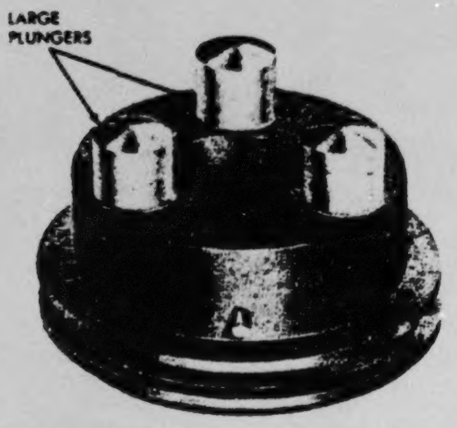

SMALL PLUNGERS
THREE-PLUNGER BLOCK ASSEMBLY
SIX-PLUNGER BLOCK ASSEMBLY

Figure 5-22. Original plunger block assemblies—fuel injector pump assemblies 7973713, 7974093, 7974355, and 8735882.

(c) The replacement plunger block assembly for fuel injector pump assemblies 7974093 and 7974355 has three larger bores, three larger plungers, and also uses three inner and outer plunger springs (fig 5-23).



RA PD 326543

Figure 5-23. Replacement plunger block assembly—fuel injector pump assemblies 7974093 and 7974355.

(2) Differences between metering head assemblies.

(a) Physical appearance and functional characteristics of metering head assemblies are the chief differences between pump assemblies. Fuel injector pump assemblies 7973713, 7974093, and 7974355 basically have a physically similar metering head. Fuel injector pump assemblies 7974093 and 7974355 metering heads, however, have additional devices mounted to them. The metering head used on fuel injector pump assembly 8735882 is completely different than those used on other fuel injector pump assemblies.

(b) Immediate identification of fuel injector pump 7973713 metering head assembly can be made from presence of a capillary tube and temperature bulb assembly mounted to the casting, and absence of an idle adjustment assembly and metering valve assembly. Some early models of fuel injector pump assembly 7974093 may have a gasket and plate secured to the obsolete solenoid mounting flange on the metering head. The metering head must have this optional construction if there is a hole through the recessed aperture into capsule chamber of the metering head.

(c) Fuel injector pumps 7974093 and 7974355 metering head assemblies are structurally similar to basic fuel injector pump 7973713 metering head assembly, but have additional devices mounted to them with applicable ports and screw holes drilled to receive the new connections and mounting screws. They both retain the temperature bulb and capillary tube assembly mounted to the metering head. Fuel injector pump 7974093 has a long capillary tube, while fuel injector pump 7974355 is shorter in length. Positive identification of a pump assembly can be made by checking the nameplate attached to the pump main body. If the manufacturer's part number is 570060, the Ordnance number is 7974093. Pump assembly 570062 corresponds to Ordnance part number 7974355.

(d) Fuel injector pump metering head assembly 8735882 is structurally different than all other metering head assemblies. It is secured to the sandwich piece assembly and main body with six metering head bolts, nuts, and washers rather than studs. It has no capillary tube and temperature bulb and no devices mounted on it.

(3) Differences between tuning springs and shims.

(a) All outer tuning springs are different, although similar in physical appearance. Spring rate of each varies from pump assembly to pump assembly and is a critical operational variable which affects fuel output.

(b) Inner tuning springs are also similar in appearance, although completely different in spring rate. They vary from pump assembly to pump assembly and affect the fuel output.

(c) Shims are used to adjust effective length of inner tuning springs. This adjustment is made during calibration of the pump assembly. Changing length of inner tuning springs affects the point at which springs contact skew shaft servo piston to influence axial movement of skew shaft. The difference between shims is their thickness, which ranges from 0.005 to 0.015 inch.

5-5. PRINCIPLES OF OPERATION—GENERAL. The SU fuel injection system operates on the principle of speed density metering. It senses the variations in engine speed, intake manifold pressure, and intake manifold temperature, and meters fuel at the desired rate for any combination of these variations. Basically, the injection pump is multiplunger axial type with a variable stroke. The main shaft of the pump is spline-coupled to the engine and driven at engine crankshaft speed. Mechanical variations on pump action are the result of an internal pressure differential. The pump uses oil from the engine lubrication system as a medium for this pressure differential.

5-6. OPERATION OF SIMMONDS PUMP. See figure 5-24.

a. **Plunger block assembly.**

(1) Actuation of the plungers in sequence in the plunger block is obtained by the axial and rotary motion of the wobble plate.

(2) The length of the plunger stroke determines the amount of fuel that will be delivered to the cylinders.

b. **Skew shaft and main shaft.**

(1) The wobble plate is fitted over the skewed portion of the skew shaft. The skew shaft, in turn, is mounted over the main shaft and is driven by a lobe on the main shaft while remaining free to move axially along the main shaft.

(2) The stroke (displacement) of the pump plunger is dependent on the angular position of the wobble plate on the skewed portion of the skew shaft.

(a) Skew shaft at bottom position - stroke length and displacement is maximum.

(b) Skew shaft at top position - stroke length and displacement is minimum.

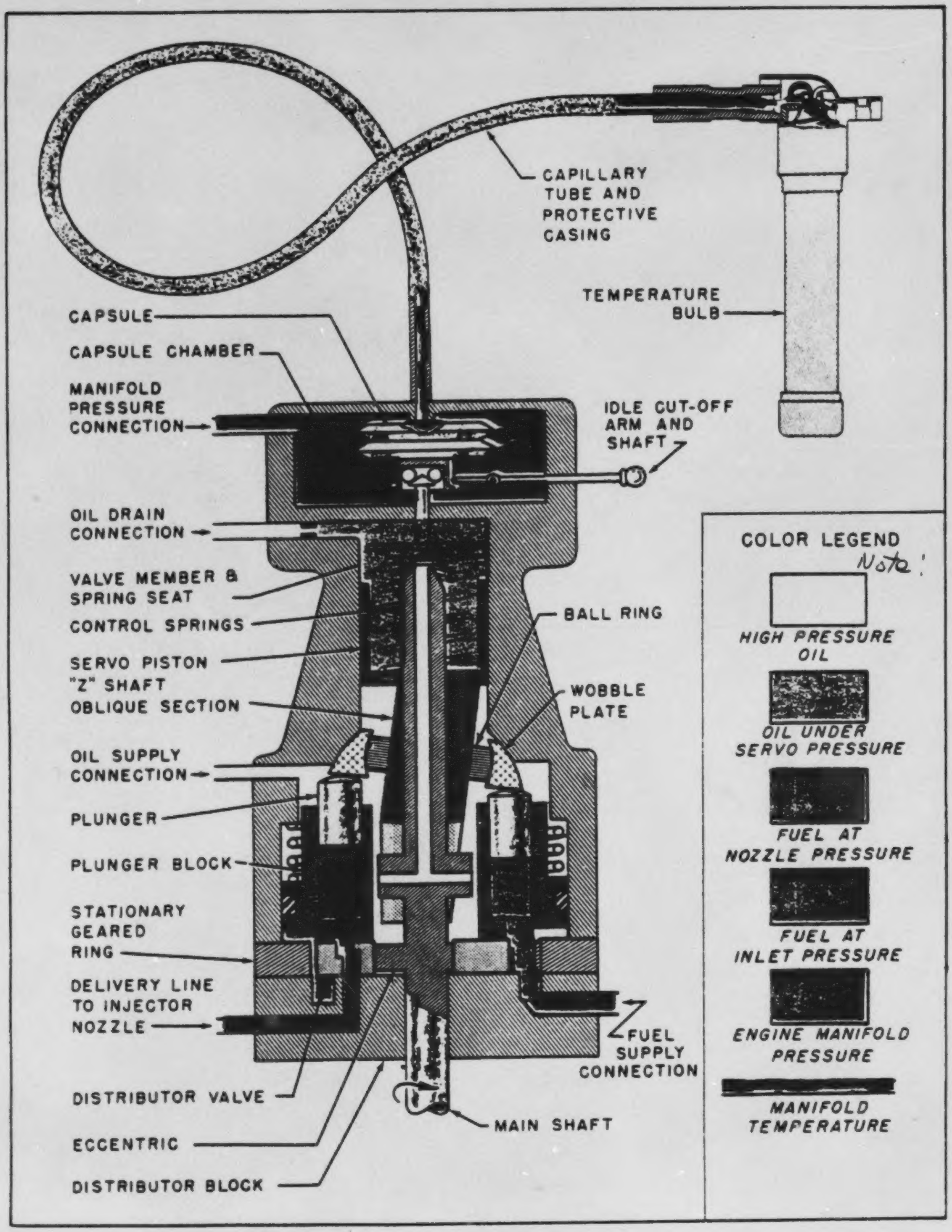

CAPILLARY TUBE AND PROTECTIVE CASING
TEMPERATURE BULB
CAPSULE
CAPSULE CHAMBER
MANIFOLD PRESSURE CONNECTION
IDLE CUT-OFF ARM AND SHAFT
OIL DRAIN CONNECTION
VALVE MEMBER & SPRING SEAT
CONTROL SPRINGS
SERVO PISTON
"Z" SHAFT OBLIQUE SECTION
BALL RING
WOBBLE PLATE
OIL SUPPLY CONNECTION
PLUNGER
PLUNGER BLOCK
STATIONARY GEARED RING
DELIVERY LINE TO INJECTOR NOZZLE
FUEL SUPPLY CONNECTION
DISTRIBUTOR VALVE
MAIN SHAFT
ECCENTRIC
DISTRIBUTOR BLOCK
COLOR LEGEND
Note!
HIGH PRESSURE OIL
OIL UNDER SERVO PRESSURE
FUEL AT NOZZLE PRESSURE
FUEL AT INLET PRESSURE
ENGINE MANIFOLD PRESSURE
MANIFOLD TEMPERATURE

Figure 5-24. SU fuel injection pump - functional schematic.

Note: Colors could not be reproduced

(3) One end of the skew shaft forms a servopiston. Two tuning springs act to keep the servo and the skew shaft in the down position.

c. Oil flow.

(1) Engine lubrication oil is admitted into the pump housing at a point just below the wobble plate. The oil is under at least 30 PSI and filtered.

(2) Oil enters the housing and passes through three slots in the spherical socket that supports the wobble plate and acts against the bottom of the servo. This oil pressure tends to move the skew shaft servo against the tuning springs toward the top of the housing to reduce the amount of fuel metered to engine cylinders.

(3) Oil under pressure also passes through the servo inlet passage at the lobe of the main shaft and up the central bore of main shaft toward the top of the skew shaft.

(4) Passage of oil out of the main shaft central bore is controlled by the servovalve and spring seat. The position of the servovalve is controlled, in turn, by the capsule position.

d. Capsule housing assembly.

(1) The capsule unit provides a means of translating intake manifold temperature and pressure changes into oil pressure changes across the servosystem, thus positioning the skew shaft and regulating plunger stroke length and fuel output.

(2) The capsule is seated on the servovalve shaft. A ball bearing is provided to allow the servovalve to rotate with the main shaft while the capsule remains stationary.

(3) Externally, the capsule is subjected to intake manifold pressure. A tube connecting the capsule to the intake manifold admits manifold pressure to the capsule chamber. The capsule is filled with dry nitrogen that contracts or expands according to temperature and pressure in the manifold.

(4) The pneumatic loading of the capsule, as a result of the internal and external pressures and external temperatures, determines its degree of longitudinal expansion and so determines, through the shaft, how far the servovalve is off its seat. The position of the servovalve retards or speeds up the flow of oil to the top side of the servo.

e. Metering fuel with high manifold pressure.

(1) Oil enters the housing and acts on the bottom of the skew shaft servo. Oil also passes through the main shaft central bore.

(2) The capsule will contract due to the increased manifold pressure and temperature. With the capsule contracted, the servovalve will open (tuning spring forces servovalve up) and allow passage of oil to the top of the skew shaft servo.

(3) Oil pressure will build up on the top side of the servo until the oil pressure on top of the servo is equal to the oil pressure on the bottom of the servo. Excess oil is metered through the restrictor and into the return oil passage.

(4) When oil pressure on both sides of the skew shaft servo are equal, a difference in pressure will be caused by the tuning springs. Hence, the tuning springs will push the servo and skew shaft down.

(5) With the skew shaft in a downward position, the wobble plate ball ring will be located at the maximum skewness point of the skew shaft. Thus, maximum plunger stroke and full delivery will result.

f. Metering fuel with low intake manifold pressure.

(1) With low intake manifold pressure, the capsule will be expanded and the servovalve opening will be closed or limited, depending on the degree of manifold pressure.

(2) With the servovalve restricting the passage of oil to the top of skew shaft servo, oil pressure on the bottom of the skew shaft servo will be greater than the pressure on the top. The skew shaft will move upward and the wobble plate will be located at the minimum skewed point of the skew shaft. Plunger travel and fuel delivery will be decreased.

(3) When the servovalve is completely closed no oil will pass to the top of the servo. The skew shaft will move to the extreme upward position due to oil pressure on the bottom of the servo, and no fuel will flow.

g. Metering variations due to temperature change. The manifold air temperature exerts pressure on the inside of the capsule unit, depending on the temperature of manifold air.

(1) High temperature - capsule tends to expand and restrict servovalve opening and, hence, decreases the amount of fuel metered.

(2) Low temperature - capsule contracts, allowing servovalve to open, which results in an increased fuel flow.

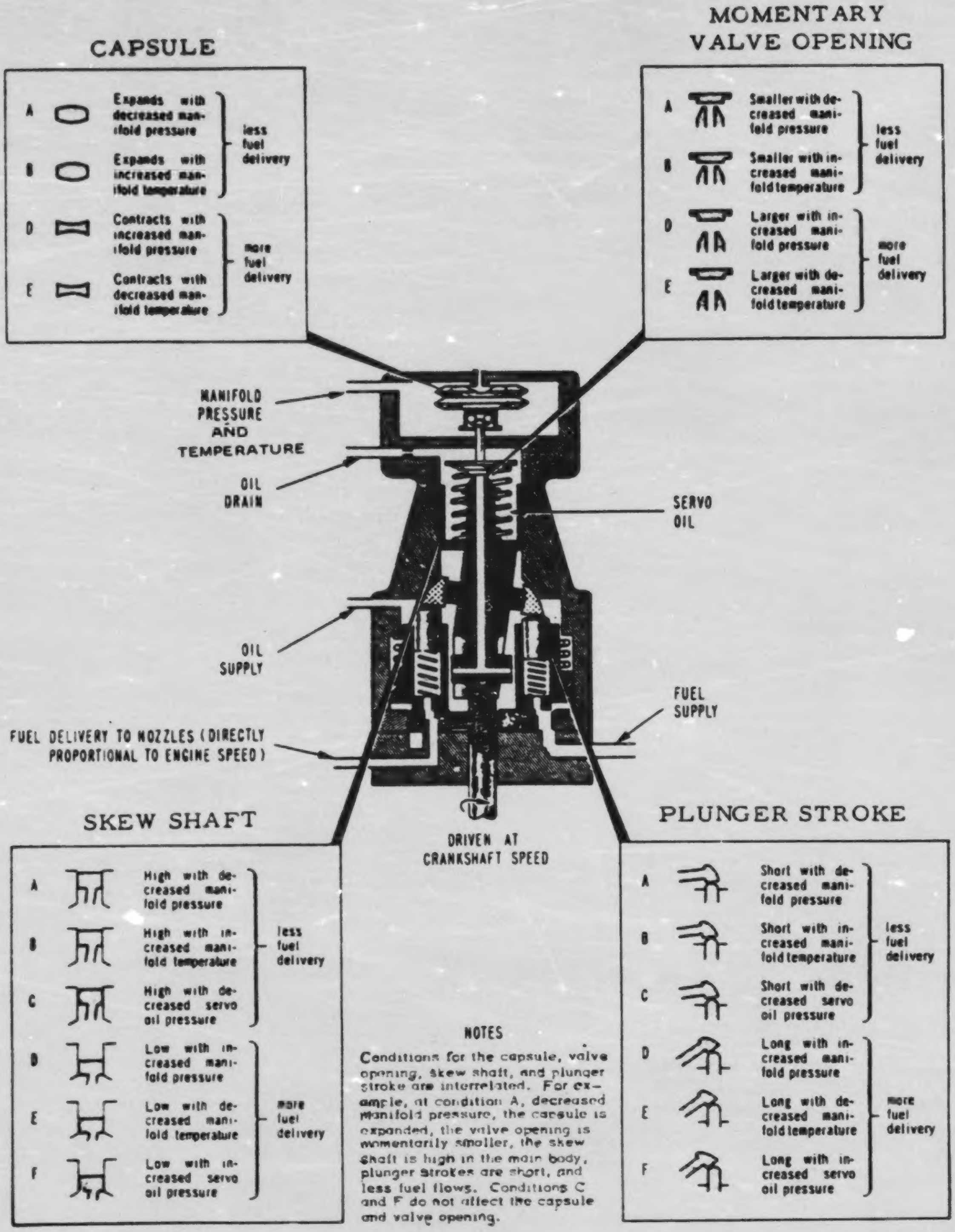
Note. - The relationship of components involved in metering is indicated in figure 5-25.

h. Fuel flow. At the bottom of the plunger block assembly is the distributor assembly consisting of the annular ring and valve. In contact with the plunger block is the distributor valve. The plunger block is spring loaded toward the distributor block, and the distributor valve is thus held in close surface contact between the two parts. The eccentric crank portion of the main shaft fits in the central bore of the distributor valve to actuate it. Fuel intake, distribution, and discharge are controlled by position of the distributor valve in relation to the plunger chamber holes, distributor block discharge holes, and intake chamber.

(1) **Fuel intake.**

(a) Fuel enters the inlet hole on the distributor block under moderate pressure. Fuel then passes into the annular passage in the distributor block and is retained in a chamber formed by the distributor block annular passage on the bottom and the plunger block and O-ring seal at the top. Fuel and fuel vapor are metered back to the fuel tank through the restrictor that is connected to the annular groove.

(b) Movement of the main shaft eccentric crank moves the distributor valve so that the plunger chamber openings are alined in proper sequence with the open space between the distributor valve and the stationary ring gear when the plungers are on their intake stroke. Hence, fuel is forced from the fuel chamber into the plunger.


CAPSULE
A
Expands with decreased manifold pressure
B
Expands with increased manifold temperature
less fuel delivery
D
Contracts with increased manifold pressure
E
Contracts with decreased manifold temperature
more fuel delivery
MOMENTARY VALVE OPENING
A
Smaller with decreased manifold pressure
B
Smaller with increased manifold temperature
less fuel delivery
D
Larger with increased manifold pressure
E
Larger with decreased manifold temperature
more fuel delivery
MANIFOLD PRESSURE AND TEMPERATURE
OIL DRAIN
SERVO OIL
OIL SUPPLY
FUEL SUPPLY
FUEL DELIVERY TO NOZZLES (DIRECTLY PROPORTIONAL TO ENGINE SPEED)
DRIVEN AT CRANKSHAFT SPEED
SKEW SHAFT
A
High with decreased manifold pressure
B
High with increased manifold temperature
C
High with decreased servo oil pressure
less fuel delivery
D
Low with increased manifold pressure
E
Low with decreased manifold temperature
F
Low with increased servo oil pressure
more fuel delivery
PLUNGER STROKE
A
Short with decreased manifold pressure
B
Short with increased manifold temperature
C
Short with decreased servo oil pressure
less fuel delivery
D
Long with increased manifold pressure
E
Long with decreased manifold temperature
F
Long with increased servo oil pressure
more fuel delivery

NOTES

Conditions for the capsule, valve opening, skew shaft, and plunger stroke are interrelated. For example, at condition A, decreased manifold pressure, the capsule is expanded, the valve opening is momentarily smaller, the skew shaft is high in the main body, plunger strokes are short, and less fuel flows. Conditions C and F do not affect the capsule and valve opening.

Figure 5-25. Functional relationships - main components.

(2) Fuel distribution. The pump is capable of providing fuel for a bank of six cylinders. Although there are six plungers, they are arranged so that they are paired in action and they actually function as three plungers. Most new applications use a three-plunger block. To accomplish delivery of the fuel to two alternate engine cylinders from a single plunger, the outer teeth on the valve gear are in a ratio of 8 to 1 to the internal teeth on the stationary ring gear. The valve gear has eight kidney-shaped ports. As the main shaft rotates, the valve gear rotates at one-eighth shaft speed and in the opposite direction. The kidney-shaped ports therefore move one-eighth turn from each revolution of the main shaft. Since passages are drilled at alternate ends of the ports it is possible to arrange for fuel delivery to the outlet ports at the desired time.

i. **Lubrication.** There is no separate lubrication system for this pump. Lubrication is accomplished by the fuel and the servo oil.

SECTION VI. SIMMONDS FUEL INJECTION SYSTEM, AUXILIARY CONTROLS AND ACCESSORIES

6-1. AUXILIARY CONTROLS REQUIRED ON SUPERCHARGED FUEL INJECTED ENGINE.

a. Idle control device (fig 6-1).

(1) An idle control device is incorporated on the injector to allow adjustment of fuel flow for greater economy at low engine speeds without affecting the basic metering curve.

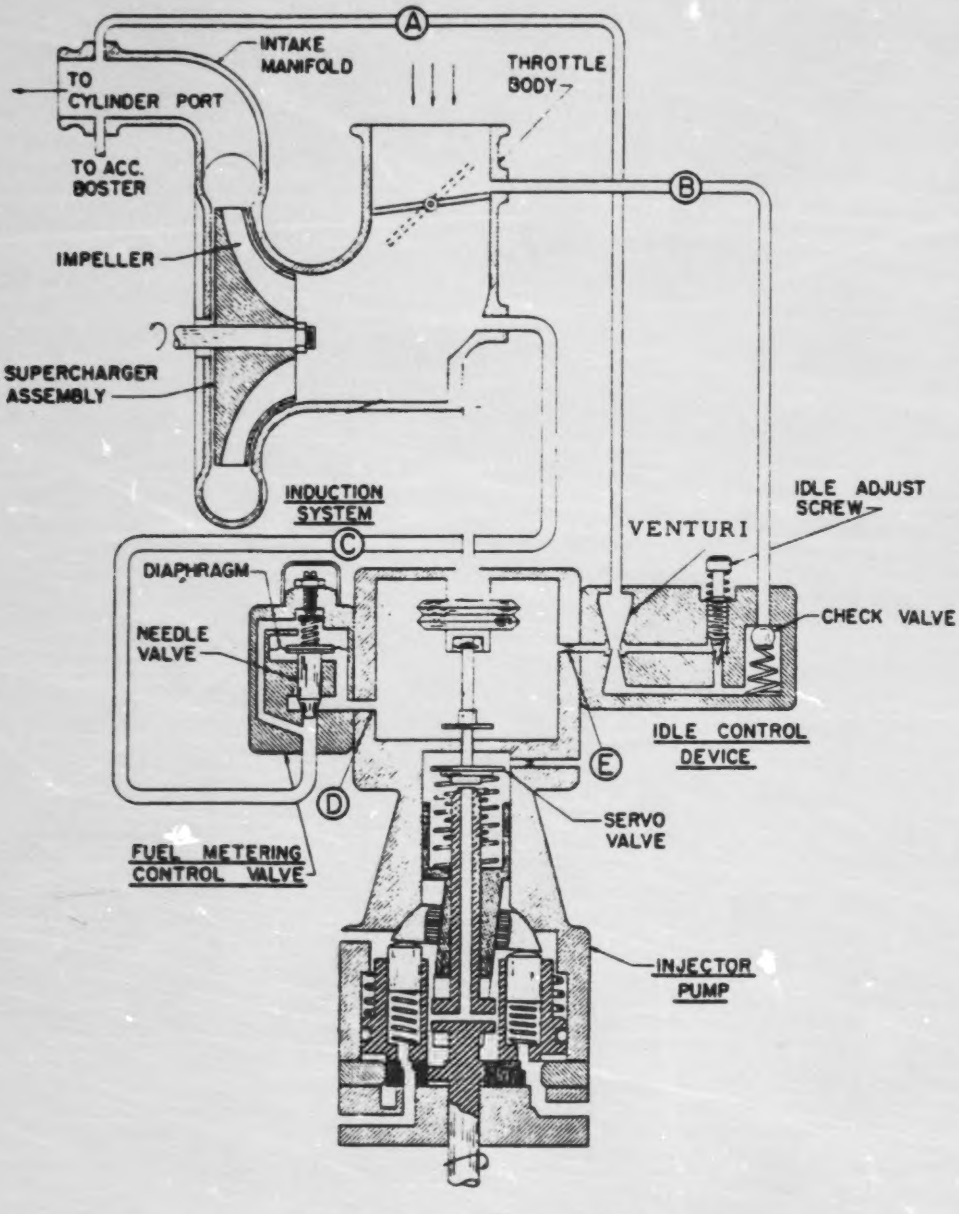

A
INTAKE MANIFOLD
TO CYLINDER PORT
THROTTLE BODY
TO ACC. BOSTER
B
IMPELLER
SUPERCHARGER ASSEMBLY
INDUCTION SYSTEM
IDLE ADJUST SCREW
VENTURI
C
DIAPHRAGM
CHECK VALVE
NEEDLE VALVE
IDLE CONTROL DEVICE
E
D
SERVO VALVE
FUEL METERING CONTROL VALVE
INJECTOR PUMP

Figure 6-1. Meter and idle.

(2) The basic component of the idle control system is a venturi, the entrance of which is connected by tube B to a hole in the air intake elbow at a point above the closed butterfly valve. The port for this tube on the idle control device is stamped "THROTTLE HOUSING." At conditions other than idle, tube A serves to transmit manifold pressure to the capsule chamber. At idle, however, tube A provides an exit for the venturi. This is caused by the higher atmospheric pressure above the butterfly in the air horn that causes the air to flow through tube B, unseat the check valve, and exit through tube A (fig 6-1). The air flowing through the venturi causes an amplified vacuum at the venturi. Since the low pressure area of the venturi is connected by a passage (E, fig 6-1) in the capsule chamber, the control pressure induced at idle bleeds off the pressure from the capsule chamber. The capsule then expands and restricts the flow of oil through the servovalve and the skew shaft will go to a lower fuel flow position. Enrichment at idle is accomplished by turning the idle screw to allow bypassing some of the airflow through the venturi, thereby reducing venturi action.

(3) An idle adjustment screw (fig 6-1) controls the position of a bypass needle valve. By turning the screw, the degree of lean-out can be adjusted. Turning the screw in will lean out fuel delivery, while turning the screw out will enrich it.

(4) The atmospheric inlet to the venturi is located in the air intake elbow at such a point that as the butterfly is opened to increase engine speed above idle, the butterfly passes the inlet. This fully exposes the hole to supercharger inlet pressure. When this pressure becomes less than intake manifold pressure, the idle device is rendered inactive due to the closing of the check valve. Tube A (fig 6-1) then transmits intake manifold pressure to the capsule chamber again.

b. Fuel metering control valve (fig 6-1).

(1) The basic injector system operates on the principle that airflow (weight of air entering the engine at a given time) varies directly to the speed of the engine and the density of the entering air. The same volumetric efficiency is assumed for all engine speeds. However, the efficiency is not constant, but decreases at high speeds and loading conditions. The "droop" of airflow at high speeds would cause the mixture to become excessively rich unless some device were used to effect a corresponding "droop" in fuel flow; as a result, the fuel metering control valve is used (fig 6-1). In effect, it reduces the pressure in the capsule chamber at high engine speeds and allows the capsule to expand, thus reducing the fuel flow by closing the servovalve.

(2) As the engine speed increases to approximately 2,000 RPM the pressure developed by the supercharger rises. This pressure enters the capsule chamber through line A and is transmitted through passage D in the capsule chamber to the bottom of the diaphragm in the metering control valve (fig 6-1). The top of the diaphragm is vented to the low pressure side of the throttle body. Hence, when air pressure is exerted on the bottom of the diaphragm it will unseat the needle valve. As the valve is opened, high pressure is bled from the capsule chamber into the low pressure line C. Lowering the pressure in the capsule chamber allows the capsule to expand and reduces the fuel flow output of the injector pump. Tension of the diaphragm spring determines the difference in pressure required to unseat the needle valve. Spring tension can be adjusted by a screw that bears on the spring.

6-2. ACCELERATION BOOSTER SYSTEM.

a. To quickly provide the additional fuel to meet rapid engine acceleration requirements, a booster device is provided (fig 6-2).

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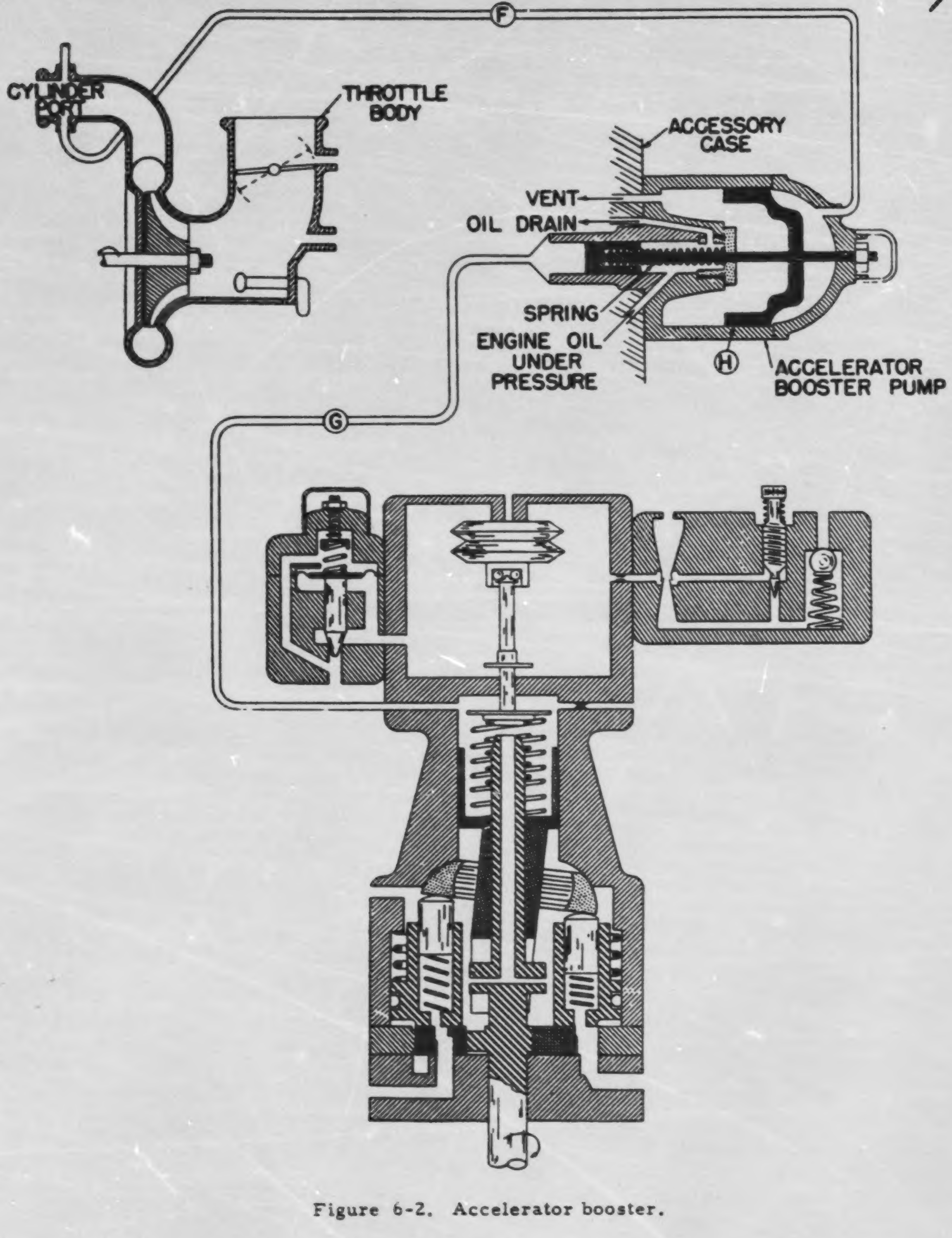

F
CYLINDER PORT
THROTTLE BODY
ACCESSORY CASE
VENT
OIL DRAIN
SPRING
ENGINE OIL UNDER PRESSURE
H
ACCELERATOR BOOSTER PUMP
G

Figure 6-2. Accelerator booster.

b. Like the injectors, the booster pumps are mounted on the accessory drive housing of the engine, with an internal oil passage in the housing providing high pressure engine oil to the boosters. Internal passages also provide an oil drain passage and a vent. The booster consists of a large vacuum piston 3 inches in diameter (H, fig 6-2) and a small accelerating oil piston 0.8 inches in diameter. Both pistons are mounted on the same shaft. The large piston is subjected to intake manifold pressure through tube F (fig 6-2) on one side and to atmospheric pressure on the other side through a vent. When the engine is running at idle or at any other constant speed, the tension of the internal spring balances the force exerted by the atmosphere and maintains the piston in equilibrium. Engine oil pressure flows into a chamber formed by the back of the small piston and retainer and is metered out to the oil drain passage. Engine oil pressure balances the injector servo oil pressure. A sudden rise of manifold pressure at acceleration upsets the equilibrium and allows the spring to extend to the full load position. The resulting movement of the large piston moves the small piston. The movement of the small piston causes a displacement of oil to the top of the injector servopiston through tube G (fig 6-2). The skew shaft is then forced to the full flow position. Conversely, a reduction in manifold pressure when engine speed levels off permits atmospheric pressure to again move the large vacuum piston. The resulting movement of the oil piston reduces the oil pressure on the top of the injector servopiston and the skew shaft moves toward the zero fuel flow position. Thus, reduced manifold pressure tends to lean the engine fuel mixture during deceleration.

6-3. APPLICATION OF CONTROLS. The fuel metering control valve and idle control device are used in the injection system of supercharged engines only, while the accelerator booster pump is used with all military engines incorporating Simmonds fuel injection systems. Figure 6-1 is a diagram illustrating the injection system and auxiliary controls as applied to the AVSI engine.

6-4. FUEL INJECTION SYSTEM ACCESSORIES.

a. **Minimum oil pressure valve.** Military engines equipped with Simmonds fuel injection systems have a minimum oil pressure valve built into the engine lubrication system. The valve is designed so that no oil is passed to the engine before the need for oil pressure to the injector system pump has been satisfied. This insures an adequate supply of oil to the injectors for proper operation of the servopiston under conditions where the engine oil pressure would fall below 50 PSI.

b. **Fuel system accessories.**

(1) **Fuel tank fuel pumps.** Electric centrifugal pumps are located in each fuel tank. They deliver fuel at 5 PSI to the main engine pumps. A switch on the instrument panel can be set for delivery of fuel from either tank. These pumps are used on the M88 recovery vehicle and the M48A2 medium tank.

(2) **Titan fuel pump.** This pump is used on all military engines employing the Simmonds fuel injection system. The Titan fuel pump mounts on the accessory case and is driven by engine accessory drive gears. It is a vane type, positive displacement pump and is capable of delivering fuel at 20 PSI to the injector pump. A metering injector pump allows fuel in excess to injector demand to be bypassed and returned to the fuel tanks or the vapor separator in the case of the M42A1 self-propelled gun. Fuel delivered to the injector pump is boosted to 50 to 70 PSI for delivery to injector nozzles.

(3) **Fuel filter.** A Purolator fuel filter, model PR 150-Z, is employed to protect the injector system against foreign materials that may be present in the fuel.

(4) Vapor separator. The vapor separator is used on the M42A1 self-propelled gun to eliminate the need for fuel tank return lines. The device is constructed similar to a carburetor float chamber. Fuel is pumped into the chamber of the separator where a float and needle device maintain a constant level. Fuel is pumped out of the vapor separator chamber and into the injector pump by the Titan pump. Fuel in excess of that required by the injector pump is metered back into the vapor chamber. A vapor line vents the chamber to the intake of the induction system. For a complete schematic of this system see figure 6-3.

(5) Primer pump. The primer pump is used to aid or supplement the fuel injector pump during initial or cold weather starts. The primer pump is located below the main instrument panel and is connected to a tee in the tank outlet line forward of the front fuel tank bulkhead and to the primer inlet port on the engine.

(6) Degasser (idle cutoff). On the AOSI 895-5 and AVI 1790-8 the degasser is of the solenoid type and is located on the fuel inlet line, and gas cutoff is accomplished before fuel enters the injector pump. It is used to shut off the engine.

Note. - Figure 6-4 is a diagram of the fuel injection system of the AVI 1790-8 engine.

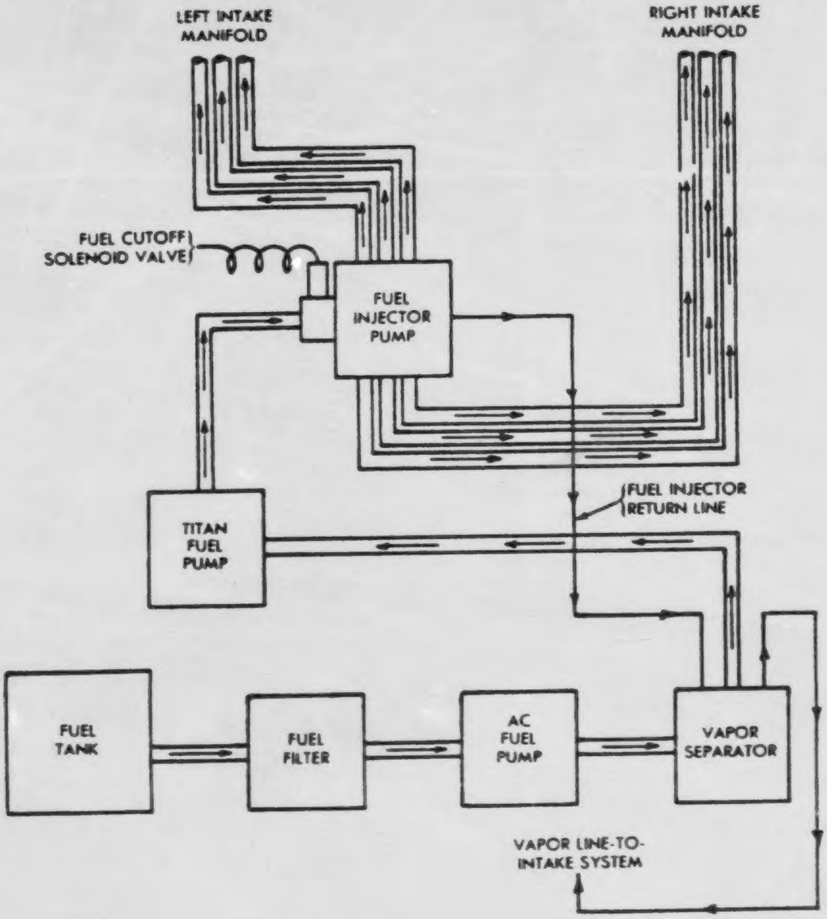

LEFT INTAKE MANIFOLD
RIGHT INTAKE MANIFOLD
FUEL CUTOFF SOLENOID VALVE
FUEL INJECTOR PUMP
FUEL INJECTOR RETURN LINE
TITAN FUEL PUMP
FUEL TANK
FUEL FILTER
AC FUEL PUMP
VAPOR SEPARATOR
VAPOR LINE-TO-INTAKE SYSTEM

Figure 6-3. Fuel injection system AVSI 895-5.

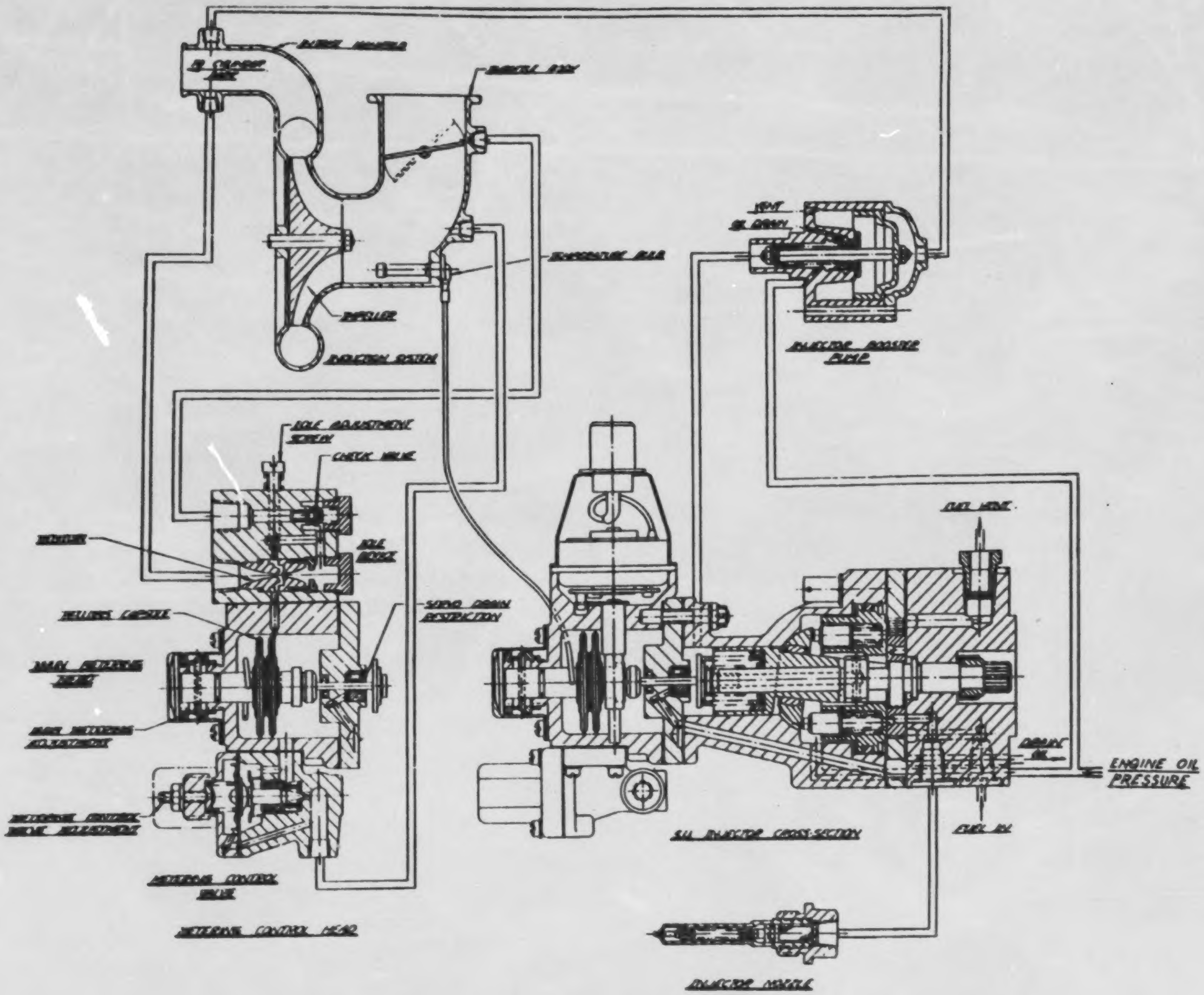

THROTTLE BODY
TEMPERATURE BULB
IMPELLER
IDLE ADJUSTMENT SCREW
CHECK VALVE
VENTURI
IDLE BOOST
BELLOWS CAPSULE
SERVO DRAIN RESTRICTION
MAIN METERING ADJUSTMENT
METERING CONTROL VALVE ADJUSTMENT
METERING CONTROL VALVE
METERING CONTROL HEAD
VENT
OIL DRAIN
INJECTOR BOOSTER PUMP
FUEL VENT
DRAIN OIL
ENGINE OIL PRESSURE
FUEL IN
SU INJECTOR CROSS-SECTION
INJECTOR NOZZLE

Figure 6-4. Fuel injection system of AVSI 1790-8.

SECTION VII. FUEL INJECTION SYSTEM MAINTENANCE (SIMMONDS)

7-1. INSTALLATION OF INJECTOR AND TIMING PROCEDURE.

a. Preinstallation procedures.

(1) Mounting surfaces must be clean before the installation is made. The gasket should be inspected for damage or foreign material that might affect the sealing of the joint between the engine mounting pad and the injector.

(2) Shipping plugs are used to protect all the port openings to exclude foreign material. These should be left in place until the unit is installed.

(3) The mounting position of the injector pump is determined by the position of the fuel vent port. It is necessary that the fuel vent port be the highest point of the injector pump to allow air bubbles to escape.

b. AVSI and AVI 1790 engines (fig 7-1).

Note. - Either the left or right bank injector can be timed first. However, considerable effort can be saved if the right bank is timed first.

(1) Remove 1R rocker box cover.

(2) Remove the power takeoff cover.

(3) Remove injector pump.

(4) Turn engine in a clockwise direction until "V Eng-1R-INJ" mark on the flywheel is in line with notch on housing and IR exhaust valve is open.

(5) Place pump on workbench, turn "A" port up, and fill with oil or solvent.

(6) Rotate the fuel injector main shaft in the direction of the arrow stamped on the distributor block while observing the oil level in "A" port.

(7) When the oil level starts to rise, reverse rotation until arrow on the butt end of the splined shaft alines with dot stamped between letters "A or D" on the bottom of the distributor block.

(8) Install injector pump on the studs; slide forward until external spline and internal spline are alined. If they do not aline, pull pump back about 2 inches, pull adapter off pad 1 inch, and turn internal splines one at a time until they aline.

(9) The procedure for the left bank is the same as for the right bank. Be certain, however, to use the "V ENG-1L-INJ" timing mark on the flywheel.

(10) To aline the left bank flywheel timing mark, continue to turn the flywheel in the normal direction of rotation for 270° from the right injector timing mark. The required open condition of the IL exhaust valve will be achieved automatically. If the left bank injector is timed independently, however, it is necessary to remove the IL rocker box cover and proceed as directed for independent timing of the right injector.

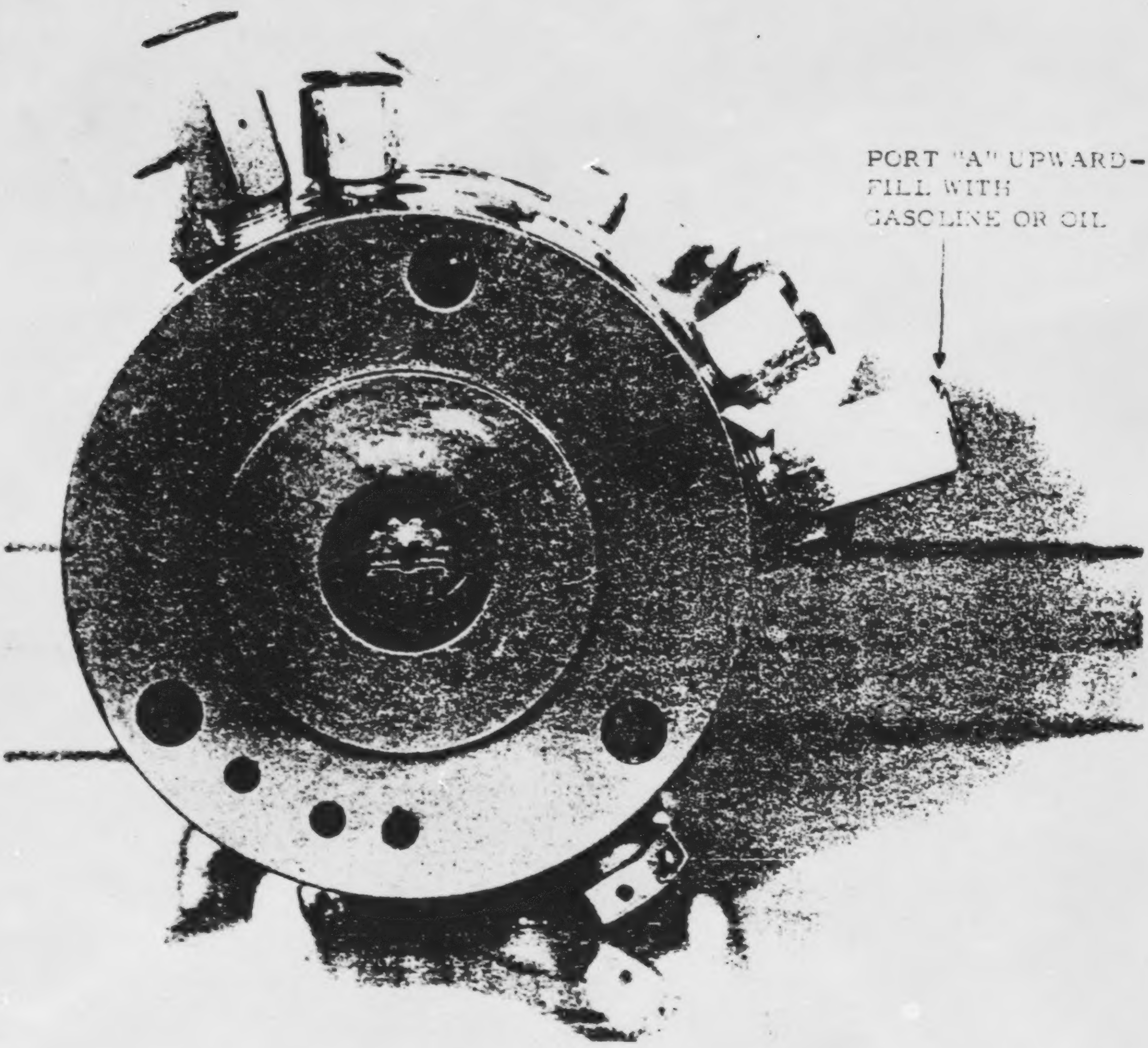


Figure 7-1. SU fuel injection pump.

(11) Install the fuel injector lines to the fuel injector pump. Each port is marked with a letter. The chart below indicates which cylinder is supplied by each port and is provided to eliminate mistakes in connecting the tubes to their proper cylinder and port. The chart applies to both injectors and must be followed exactly.

Note. - Do not use thread lubricants or sealing compounds on nozzle line fittings.

Port	A	B	C	D	E	F
Cylinder	1	5	3	6	2	4

(12) Install fuel return, oil return, and auxiliary control lines and make solenoid electrical connections.

7-2. ADJUSTMENTS AND TESTS.

a. **Idle adjustment.** When the engine is warm, set the idle adjustment screws for best idling characteristics and balance. Normally, this will be achieved by backing off adjustment screws one and one-half turns from the fully closed position. If the idle adjustment shows no reaction, check for plugged lines and loose fittings.

b. **Metering control valve adjustment.** The metering control valve adjustment must not be changed since special equipment is required for recalibration.

c. **Fuel vent plug.** This plug must not be tampered with. It has a critical orifice which maintains the correct fuel pressure within the pump. The port for this plug is stamped "VENT" on the distributor block.

d. **Titan pump.** The fuel pressure at the outlet of the Titan pump should be 18 to 22 PSI at all engine speeds above 650 RPM. If the pressure is not within these tolerances, adjust to 20 PSI at 1,000 RPM by loosening the large hex nut and turning the slotted screw—clockwise to increase the pressure and counterclockwise to decrease the pressure. Tighten adjusting nut and lock wire.

e. **Injector nozzles.** When the injector nozzles are functioning properly, a slight mouse-like squeak will be audible. If the squeak is absent, the nozzle is leaking and should be replaced.

f. **Vapor separator (found in M42A1 self-propelled, twin 40mm gun vehicle only).** The vapor separator should pass fuel to the Titan pump at the "AC" fuel pump pressure of 3 to 5 PSI. If this does not occur, investigate the valve seat and O-ring under the cover on the front of the vapor separator housing and follow up with "AC" fuel pump output checks.

7-3. PREVENTIVE MAINTENANCE. Considerable emphasis should be placed on keeping the fuel supply free of foreign matter. Fuel filters should be checked daily for water or other foreign material. Oil filters should be checked periodically for foreign materials. If evidence of foreign material is present, the system should be drained and flushed. Check all lines for tightness and condition. Loose connections can cause erratic engine operation.

7-4. TROUBLESHOOTING PROCEDURES - GENERAL.

a. The injector pumps are precision mechanisms and are not subject to undue malfunctions if given reasonable care.

b. Troubleshooting is a systematic isolation of defective components by means of an analysis of vehicle trouble symptoms, testing to determine the defective component, and applying the best remedy.

c. Intelligent diagnosis procedures will result in savings in time and money. The defective system should be checked first for incipient defects, such as loose lines and components, before major failure is suspected. Question the vehicle driver to obtain the maximum number of observed symptoms. The greater the number of trouble symptoms that can be evaluated, the easier will be the isolation of the defect.

d. The following charts are provided as a guide for diagnosing malfunctions of Simmonds fuel injection systems. Do not overlook the possibility of malfunctions in related systems and components. The chart cannot possibly cover all the possible deficiencies and is meant as a guide only.

7-5. TYPICAL TROUBLES - DIAGNOSIS AND REMEDY.

a. Engine running rich or emitting smoke.

PROBABLE CAUSE	REMEDY
Restricted oil supply or low oil pressure.	Check oil lines for restriction; check oil pressure (minimum 28 PSI).
Leaking injector nozzles.	Check cylinder head temperatures; replace the injector nozzles of the cold cylinders.
Fuel supply pressure excessively high.	Check vapor separator (M42A1). Readjust fuel pump output pressure to 20 PSI at 1,000 RPM.
Leak in manifold line.	Check and tighten fittings on the lines.
Ice in servo oil (extreme cold weather).	Heat injector pump.
Rich mixture. Metering valve closed or diaphragm ruptured.	Replace metering valve assembly.
At idle condition - loose lines or leak between capsule housing mounting face and idle adjustment housing.	Tighten lines, check gasket, and tighten mounting screws.

b. Lack of maximum power.

PROBABLE CAUSE	REMEDY
Leak in air induction system (supercharged engines).	Check tubing and capsule housing for leaks. Tighten all mounting screws and fittings.
Low fuel supply pressure.	Check fuel pump output pressure. If defective, replace pumps.
Throttle linkage limiting the motion of the throttle butterfly.	Check throttle linkage and butterfly opening. Correct adjustment.
Injector pump not properly timed to the engine.	Check the timing. Retime if necessary.

c. Oil dilution.

PROBABLE CAUSE	REMEDY
Leak between plunger block and body.	Replace the injector pump.

d. Poor acceleration.

PROBABLE CAUSE	REMEDY
Dirt in injector nozzles.	Run engine at a high RPM for a few seconds to clear injector nozzles. If this is not effective, remove injector nozzles and clean or replace as described for poor idling.
Restricted oil supply.	Check oil pressure at injector pump oil inlet. Clean or replace oil passage or lines.
Leak in air induction system (supercharged engines).	Check induction tubing, fittings, and capsule housing for leaks. Tighten all mounting nuts.
Leaky or defective accelerator booster pump.	Check booster pump for leaks or stuck piston. Replace pump if necessary.
Lean mixture.	Replace injector pump.
Sticking skew shaft.	Replace injector pump.

e. Engine running lean.

PROBABLE CAUSE	REMEDY
Low fuel supply.	Check fuel supply in tank. Fill if low.
Low fuel pressure.	Check fuel pressure at injector pump inlet. This should be 10 to 20 PSI. Adjust or replace pump.
Incorrect injector pump calibration.	Replace injector unit.
Leaking capsule.	Replace injector unit.

f. Poor idling.

PROBABLE CAUSE	REMEDY
Clogged injector nozzles.	Run engine at full power to clear injector nozzles. Check cylinder head temperatures and remove injector nozzle from the cold cylinder. Replace with another injector nozzle.

PROBABLE CAUSE	REMEDY
	Note. - In an emergency, the injector nozzle may be cleaned by attaching it to a primer pump (or other source of pressure capable of producing 100 PSI) to clean it from foreign matter. When clean, the injector spray pattern will be a smooth wall cone. Note. - Do not take the injector apart or turn the pintle in the body.
Low oil pressure	Check the lines for restrictions. Check the oil pressure delivery to injector pump; minimum pressure should be 28 PSI.
Pump not properly timed to the engine.	Check the timing. Retime if necessary.
Lean mixture. Idle adjustment screw opened too far. Engine pops at idle.	Turn idle adjustment screw in until popping is eliminated.

g. **Injector pump not delivering fuel.** This trouble is indicated by failure of the engine to start.

PROBABLE CAUSE	REMEDY
Injector pump not driven in direction of rotation indicated by the arrow.	Check injector pump against appropriate technical manual. Install proper pump.
Sheared drive shaft.	Replace pump. Return oil pump to ordnance.
Fuel lines improperly installed for direction or rotation.	Check appropriate engine manual for fuel piping diagram. Install correctly.
Fuel line restricted.	Make certain that the inlet line is not restricted. Be sure the fuel selector valve is turned to the full open position for tank in use.
No fuel pressure.	Check fuel pumps. Replace if necessary.
Air bubbles in fuel system.	Check fuel vent. Clean if necessary.

h. **Engine popping under load conditions.**

PROBABLE CAUSE	REMEDY
Leak between capsule housing mounting face and metering valve body.	Check gasket. Tighten the mounting screws.
Lean mixture. Metering valve hanging open.	Replace metering valve assembly.

PROBABLE CAUSE	REMEDY
Leaky injector nozzle.	Remove nozzle suspected of leaking. Blow into the nozzle. Escape of air through nozzle valve indicates leaking. Replace nozzle or nozzles as necessary.
Lean mixture.	Replace injector pump. Old pump must be recalibrated.

7-6. CALIBRATION OF SIMMONDS FUEL INJECTORS USING TEST STAND 4910-817-7431.

a. General.

(1) Fuel flow calibration. Fuel flow calibration is the measurement of the fuel output of the fuel injector pump on an appropriate test stand. The comparison of this measured output with the required output is established by the injector pump's fuel flow calibration curve. Adjustments are made on the pump during calibration so that its output will fall within the tolerance of the fuel flow calibration curve. All injector pumps discussed here are calibrated using the fuel injector pump test stand 4910-817-7431 (fig 7-2). Accessories required for testing pumps and nozzles are shown in figure 7-3. Description of the test stand is discussed in b below.

(2) Nozzle testing. Nozzle testing on the test stand includes checking the spray pattern, crack pressure, and dribble of the various nozzles used.

(3) Metering valve calibration. Injector pumps used on supercharged engines have a metering valve assembly which must be calibrated after repair and rebuild. Calibration of this device consists of comparing its pressure regulating function with its established calibration curve and is also performed on the test stand. Adjustments are made during calibration to make its operation fall within the tolerances of the calibration chart.

b. Description of test stand.

(1) General. The test stand is capable of pretesting, calibrating, and troubleshooting most gasoline, multifuel, and diesel fuel injector pumps. This electric powered unit is capable of testing all of the fuel injector pumps covered here. Simulated engine conditions are obtained from the test stand which drives the pump at engine crankshaft speed and permits measurement of its fuel output at varying loads and rotational speeds.

(2) Test stand main drive. The test stand main drive mechanism is composed of a 10 hp motor whose power requirements are 220/440 volts, 60-cycle, 3-phase AC; and a variable speed mechanism capable of driving the fuel injector pump under test at any desired speed, in either direction of rotation, within the range of 150 to 3,600 RPM. Speed of rotation is adjusted by operating the speed adjusting buttons and observing the revolutions per minute indicated on the tachometer. The range of the tachometer is from 0 to 4,000 RPM.

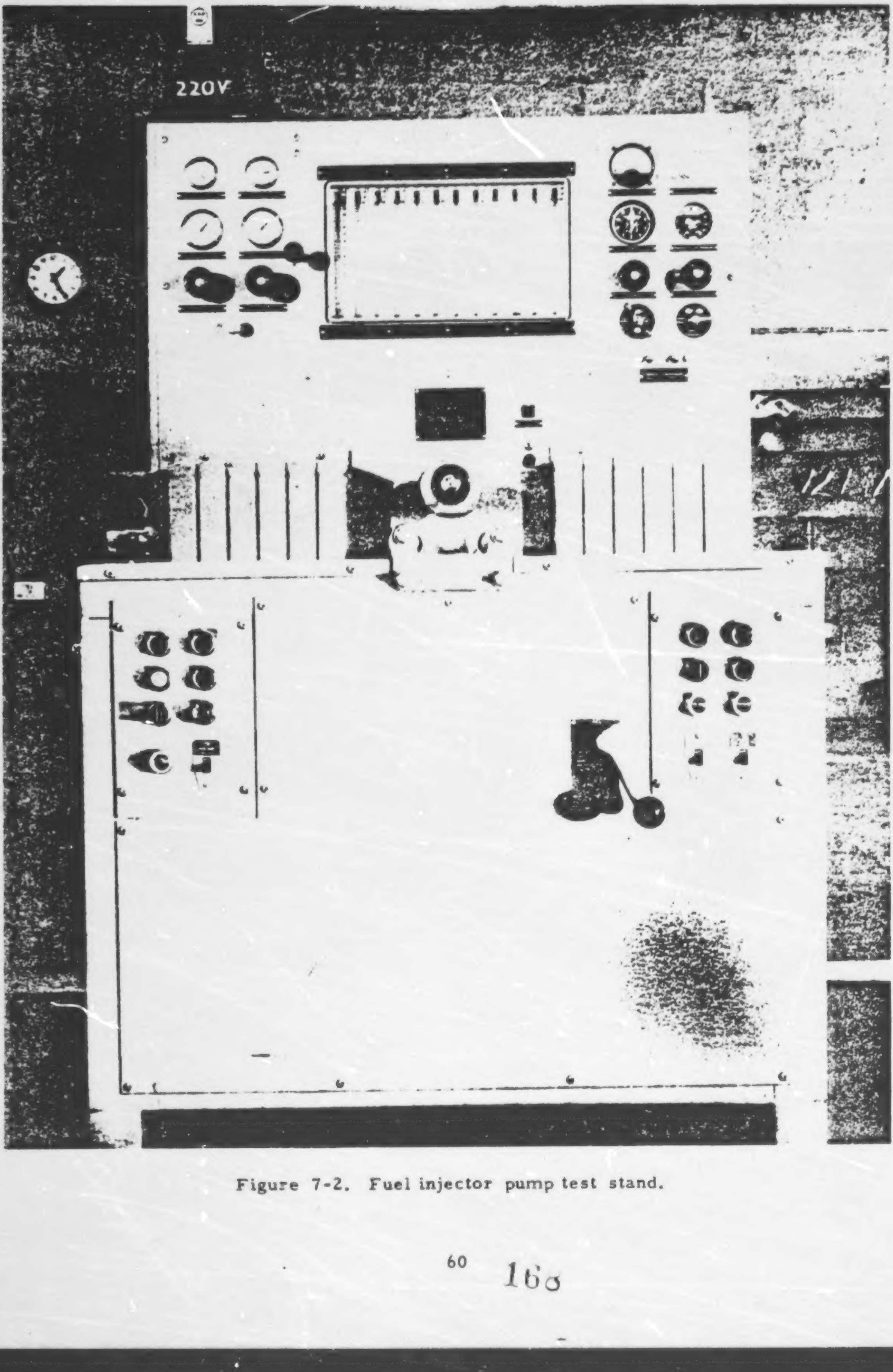


Figure 7-2. Fuel injector pump test stand.

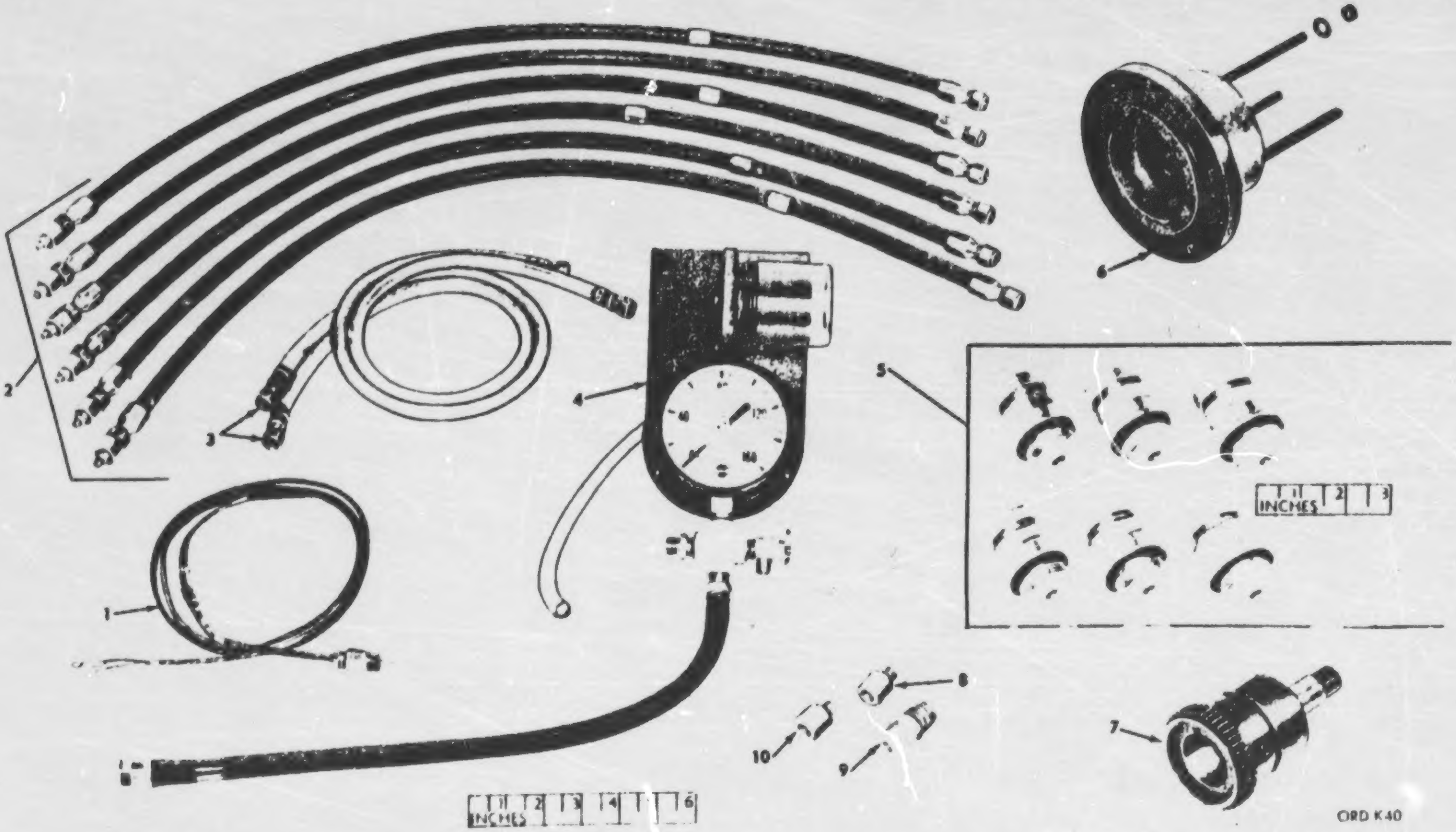

1
2
3
4
5
6
7
8
9
10
INCHES 1 2 3
INCHES 1 2 3 4 5 6
ORD K40

Figure 7-3. Injector pump test stand accessories.

(3) Manifold vacuum pressure system. Simulated engine manifold pressure or vacuum is supplied to the fuel injector pump undergoing calibration on the test stand. Vacuum or pressure is supplied to the pump depending upon the position of the vacuum pressure reversing valve located on the upper right-hand control panel. The system is adjustable to any vacuum or pressure between 5 and 50 inches of mercury (HG). Vacuum is controlled by adjusting the manifold vacuum regulator knob, which is found on the same panel. Manifold pressure is controlled by the manifold pressure regulator knob to the right of the vacuum regulator. The amount of vacuum or pressure supplied to the pump being calibrated is indicated on the manifold vacuum pressure gage located above the regulator knobs. The scale of the manifold vacuum pressure gage is calibrated in inches of mercury (HG) absolute and has a range of 0 to 60 inches of mercury. The gage also has a manual adjustment to correct for barometric pressure at the test stand location. To measure the simulated manifold vacuum or pressure supplied to the injector pump, set the manifold pressure selector valve to the corresponding position. When the manifold pressure capsule chamber pressure selector valve is placed in the capsule pressure position, the pressure within the chamber containing the capsule is measured. When the valve is placed in the manifold pressure position, the pressure or vacuum delivered to the injector pump's manifold pressure connection is measured.

(4) Controlled heat chamber for temperature sensing bulb. A temperature controlled chamber which will hold the sensing bulb is located on the front panel of the test stand to the right of the drive coupling. It is used to control the temperature of the sensing bulb during calibration of pumps so equipped. The temperature in the chamber may be adjusted to any desired setting between ambience and 130° F. A temperature gage located on the right-hand face of the test stand indicates the chamber temperature.

(5) Fuel and oil supply system.

(a) The fuel supply system consists of an internal supply pump and an adjustable fuel pressure regulator knob located on the top left control panel. The delivery pressure of fuel from the supply pump is adjustable between 0 and 60 PSI. This pressure is read from the fuel pressure gage above the regulator. Also included in the fuel system is an internal 9.7-gallon fuel tank and three-stage filtering system.

(b) The servo oil supply system also has an internal supply pump and an adjustable pressure regulator knob located alongside the fuel pressure regulator. The delivery pressure of servo oil from the supply pump is adjustable between 0 and 100 PSI. This pressure is read from the oil pressure gage above the regulator knob. Also included in the oil system is an internal 2-gallon oil tank and one oil filter.

(6) Air pump. The air pump is used in the vacuum pressure system. The pump is driven by the same auxiliary motor that drives the fuel and oil supply pumps.

(7) Burettes. The test stand is equipped with 12 burettes which are used to measure an injector pump's output in cubic centimeters. Each burette will measure up to 160 cc's. To cause fuel to flow into the burettes, the operator must first select the 500 count or 1,000 count position on the count selector and push the start count button while the pump being tested is operating at the desired RPM. The counting mechanism will automatically cause fuel to flow into the burettes for the number of revolutions selected on the count selector. When the test is complete the fuel is drained from the burettes by pushing the dumping lever to the left of the burettes all the way in.

(8) **Injector nozzle testing system.**

(a) Since the pressures required to test gasoline nozzles are much less than those required for diesel nozzles, two pumps are provided with the stand. The gasoline injector nozzle tester uses the test stand primer pump to supply the fuel pressure required to test gas injector nozzles. The tester consists of a pressure gage that reads up to 160 PSI and a transparent chamber into which the fuel is sprayed.

(b) Most diesel injection systems employ injector nozzles that open at pressures above 2,500 PSI. A separate pump and special adapters are provided for testing these nozzles.

(9) **Test stand accessories.** The necessary drive adapters, lines, nozzles, and mounting brackets are provided for testing Simmonds SU, PSB 6, PSB 12 BT, and APE 6BB injector pumps. Additional adapters and other required equipment can be obtained for testing most of the fuel injector systems used in modern vehicles.

c. Preparation of test stand for calibration.

(1) Before calibrating each pump, make sure that the fuel and oil tanks are filled to a safe level. Add calibrating oil to the fuel tank and SAE 30 oil to the oil tank as required.

(2) When a new test stand is placed into operation and when normal calibration maintenance inspections on the test stand are being performed, it will be necessary to check the manifold vacuum pressure gage to read the prevailing wet barometric pressure.

d. Installing Simmonds SU pump on test stand.

(1) Select the set of adapters that are designed for use with the Simmonds pump. Mount the pump to the mounting bracket and place the pump on the test stand mounting rails, making sure that the splines on the drive coupling match.

(2) Fuel injector nozzles must then be mounted on the test stand and connected to the injector pump, using flexible lines.

(3) One fuel inlet port on the pump must be plugged, the other one connected to the test stand outlet marked "FUEL PRESS." The vent port in the pump is connected to the fuel return.

(4) Oil inlet and return lines are connected to the pump mounting adapter and must be connected properly. Connect the outlet marked "OIL PRESS" to the fitting nearest it on the mounting bracket and the other fitting on the mounting bracket to the "OIL RETURN."

(5) Connect an air line from the outlet on the test stand marked "MANIFOLD INLET" to the manifold air pressure connection on the pump metering head. Make sure that all other holes in the head are plugged, or oil and air will escape from the pump.

(6) If the pump is equipped with a sensing bulb, the bulb must be placed in the heat chamber.

e. Test stand operation with fuel injector pump installed.

(1) **Heating test stand fuel, servo oil, and temperature bulb chamber.**

(a) Turn on auxiliary motor switch to start operation of fuel, servo oil, and air pump systems. Servo oil pressure should always be at least 10 PSI higher than fuel pressure on gage. If servo oil pressure, as indicated by servo oil pressure gage, is not 10 PSI higher than fuel pressure, adjust servo oil pressure regulator knob until gage reads 10 PSI higher than fuel pressure gage.

(b) Turn on heater switches to energize heater elements in servo oil tank and in chamber. Check chamber temperature on gage. Temperature should be 100° F. Check servo oil temperature on gage. Temperature must be 170° to 180° F. Temperatures are automatically controlled by internal thermostats preset by the test stand manufacturer. If chamber and servo oil temperatures are not correct after a suitable warmup period, consult the test stand operator's manual for thermostat adjustment procedures.

(c) When servo oil and chamber temperatures are correct, increase servo oil pressure to 60 PSI by adjusting knob and reading from gage. Adjust fuel pressure to 20 PSI, using knob and reading from gage.

Note. - Some variations in fuel and servo oil pressures will be noted during pump fuel flow calibration procedures. Small variations are normal and compensation for them is unnecessary.

(2) Starting test stand main drive.

(a) Shift test stand to high range and push the start button. Push fast button and adjust the pump speed to 1,000 RPM.

(b) Select the 500-count position on the count selector switch. Pull out the pumping lever and push the start count button. This wets the burettes and makes possible more accurate readings. After 500 revolutions of the pump, the counter is automatically reset and the burettes are bypassed by the fuel flow. If no fuel flows into the burettes after 30 seconds, stop the test stand and check for proper rotation.

(c) Push fast button and adjust speed to 1,800 RPM plus or minus 50 RPM. All calibration tests are made at this speed.

f. Fuel flow calibration, Simmonds injector pump No 7973713.

Note. - This pump is being used as an example. The test procedures for all Simmonds pumps are the same. Only the fuel output requirements change.

(1) The fuel flow calibration consists of measuring the fuel output of the pump at certain specified absolute wet manifold pressure MAP (maximum absolute pressure) settings and comparing this measured output with the output required by the pump's calibration curve. If pump output does not fall within tolerances indicated, then it must be adjusted as calibration procedures are performed.

(2) Check for proper connections between pump and test stand. Make sure fuel, servo oil, and bulb chamber temperatures are correctly set. Check fuel and servo oil pressures. Make sure that temperature bulb is inserted in chamber, if required. Make sure gage is set to compensate for barometric pressure conditions at test stand location.

(3) Refer to figure 7-4 for the calibration curve. Make a tracing of this curve for plotting points during calibration procedures. Set selector valve to manifold pressure position. Adjust reversing valve to vacuum position.

Note. - Measurements of fuel flow must be made from approximately maximum MAP to approximately minimum MAP, and then in reverse order from minimum to maximum MAP as indicated in figure 7-4.

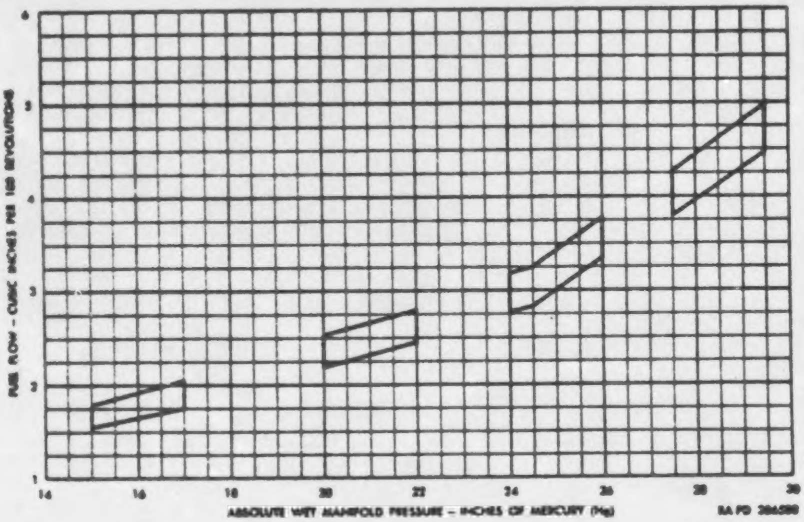


Figure 7-4. Fuel injector pump No 7973713 fuel flow calibration chart.

(a) Adjust the vacuum regulator so that the gage reads 29 inches of mercury (HG) maximum absolute pressure, a near maximum figure from the curve shown above. Pull out the dumping lever and push the start count button. When the fuel stops flowing into the burettes, note the amount in each burette and add together.

Note. - The pump fuel output is collected automatically for 500 revolutions in burettes which are calibrated in cubic centimeters. Since the fuel flow calibration curve in figure 7-4 is calibrated in terms of cubic inches per 100 revolutions, it is necessary to convert the sum of burette readings taken into cubic inches per 100 revolutions for plotting purposes. To convert, divide the sum reading of all burettes by 82 and plot this point on the tracing of figure 7-4. It is necessary to follow this conversion procedure before plotting any point in subsequent fuel flow calibration procedures.

(b) The plotted fuel flow points for 29 inches Hg MAP, taken in (a) above, must fall on the 29 inches of mercury (Hg) line and within the parallel curves in figure 7-4. If it does, continue with (c) and (d) below. However, if the point is above the upper curve or below the bottom curve, an adjustment of capsule position is necessary. Refer to figure 7-5 that shows curves taken when capsule needs adjusting, as indicated by dotted line curves above or below normal curve.

Note. - Capsule position is adjusted by turning the capsule adjustment nuts (fig 7-6) either clockwise or counterclockwise. If the nuts are lock wired, break and remove locking wire.

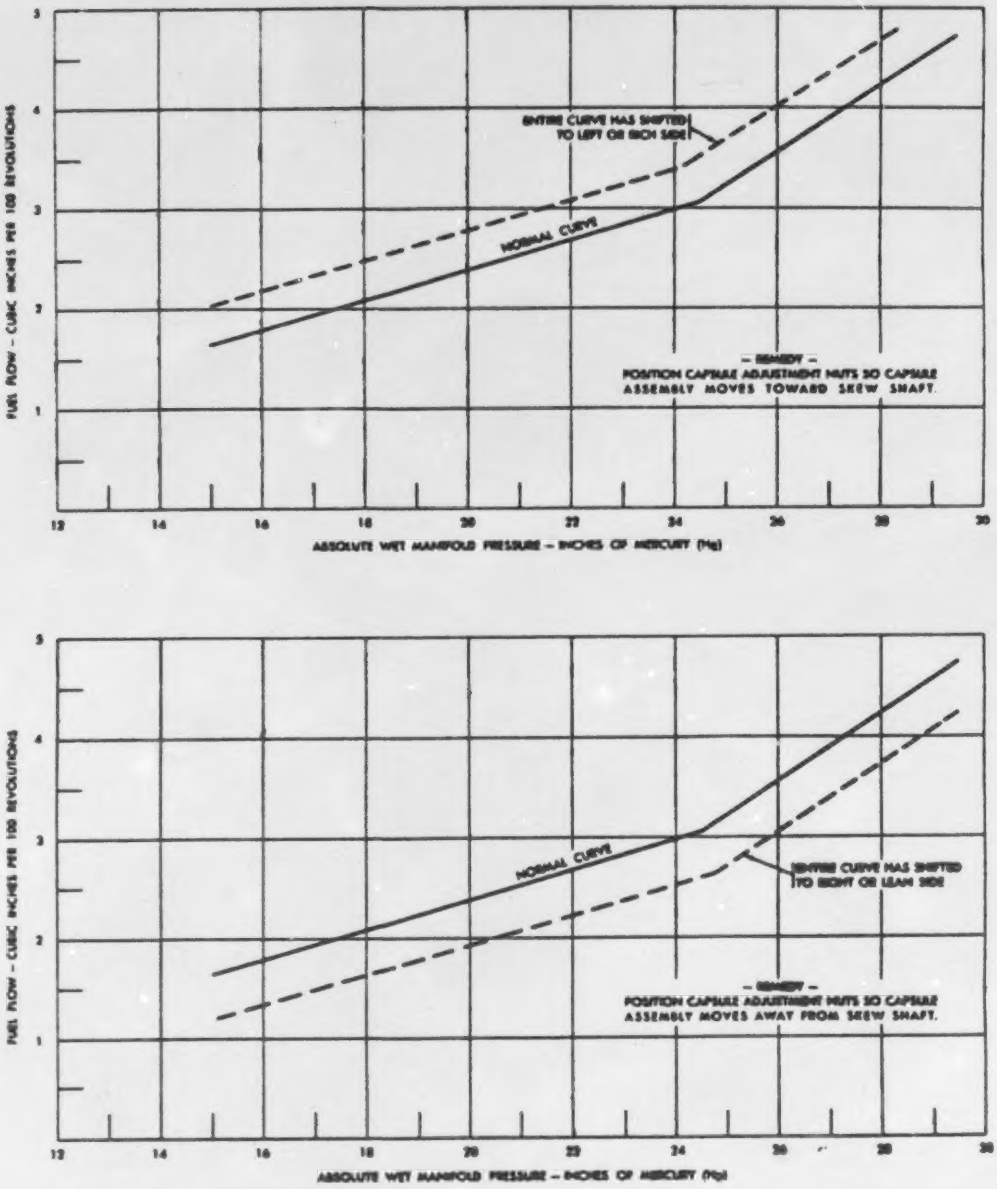


Figure 7-5. Effects of capsule adjustment on fuel flow calibration curve.

(c) If the plotted point is above the upper curve, as shown in example figure 7-5, the pump is supplying too much fuel and the top capsule adjustment nut (fig 7-6) must be turned clockwise carefully. This nut bears against cross-pin (E, fig 7-6). Turning nut (E, fig 7-6) clockwise causes the cross-pin that is inserted in the stalk of capsule assembly (A, fig 7-6) to move the capsule assembly (A, fig 7-6) closer to the sandwich piece assembly (F, fig 7-7) and reduce fuel output. Before turning the top adjustment nut, it is necessary to loosen the bottom nut (D, fig 7-6) a few turns clockwise. This allows the cross-pin to move downward freely. Turn the top adjustment nut carefully clockwise so that a slight downward movement of the cross-pin takes place. Turn bottom nut counterclockwise to secure cross-pin. Rerun the fuel flow calibration at 29 inches of mercury (Hg) as in (a) above. Plot points on curve tracing. If plotted point is not within tolerances shown in figure 7-4, readjust top nut and rerun fuel flow at 29 inches of mercury (Hg) until plotted point falls within parallel curves indicated in figure 7-4. The amount of adjustment to the top nut is different in each case and only experience will enable adjustments to be made quickly.

(d) If the plotted point is below the lower curve, as shown in example figure 7-5, the pump is not supplying enough fuel. Turn the top capsule adjustment nut slightly (a few turns) counterclockwise. Turn bottom nut counterclockwise to move cross-pin and capsule assembly toward top capsule adjustment nut. Repeat adjustments until plotted point is within tolerances shown in figure 7-4.

(e) When 29-inch mercury (Hg) fuel flow point is within tolerance, take fuel flow measurements and plot points 28, 26, 25, and 24 inches of mercury (Hg). Follow procedures given in (a) above. If all plotted points fall within parallel curves shown in figure 7-4, continue calibration and take fuel flow measurements at 22, 20, 17, and 15 inches of mercury (Hg). If all points fall within curves shown in figure 7-4, the pump is properly calibrated.

(f) However, if plotted points for 28 through 24 inches of mercury (Hg) do not fall within tolerances, refer to figure 7-8. Remove pump metering head assembly (H, fig 7-7), sandwich piece assembly (F, fig 7-7), and outer tuning spring (C, fig 7-7). Replace outer tuning spring (C, fig 7-7), reassemble pump, and rerun steps in (a), (b), and (e) above until all plotted points fall within tolerances shown in figure 7-4.

(g) If points plotted in (e) above for 22 through 15 inches of mercury (Hg) do not fall within tolerances, refer to figure 7-9. Remove pump metering head assembly (H, fig 7-7), sandwich piece assembly (F, fig 7-7), and inner tuning spring (D, fig 7-7). Replace inner tuning spring (D, fig 7-7), reassemble pump, and rerun steps in (a), (b), (e), and (f) above until all plotted points fall within the tolerances shown in figure 7-4.

(h) If pump curve cannot be brought within tolerances, refer to figure 7-8. A distinct bend, or knee, should occur at the MAP point (A) indicated. If bend does not occur at proper point, inner tuning spring shim changes are necessary. Remove metering head assembly (H, fig 7-7), sandwich piece assembly (F, fig 7-7), and shim(s) (B, fig 7-7) from pump. Change shim(s) thickness as necessary (fig 7-10). Reassemble pump and rerun steps in (a) through (c) above and (a) through (c) below, as necessary to bring all plotted points within tolerances shown in figure 7-4.

(4) After all adjustments have been made and all plotted points fall within the tolerances indicated in figure 7-4, the pump is properly calibrated and ready for removal from test stand. Use following shutdown and removal procedures:

(a) Reduce test stand main drive speed.

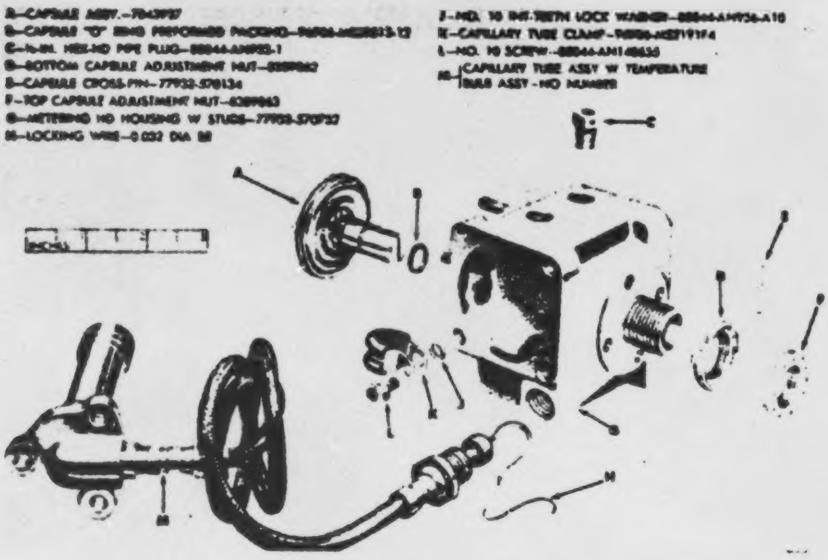
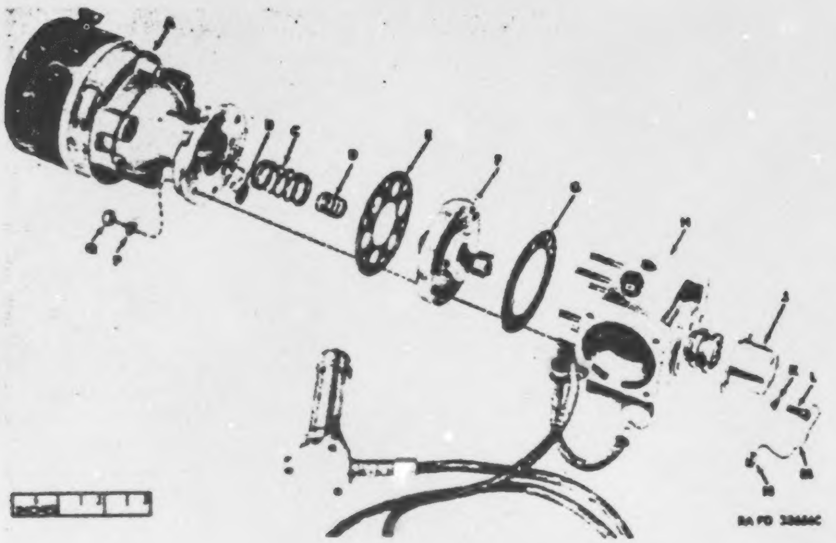
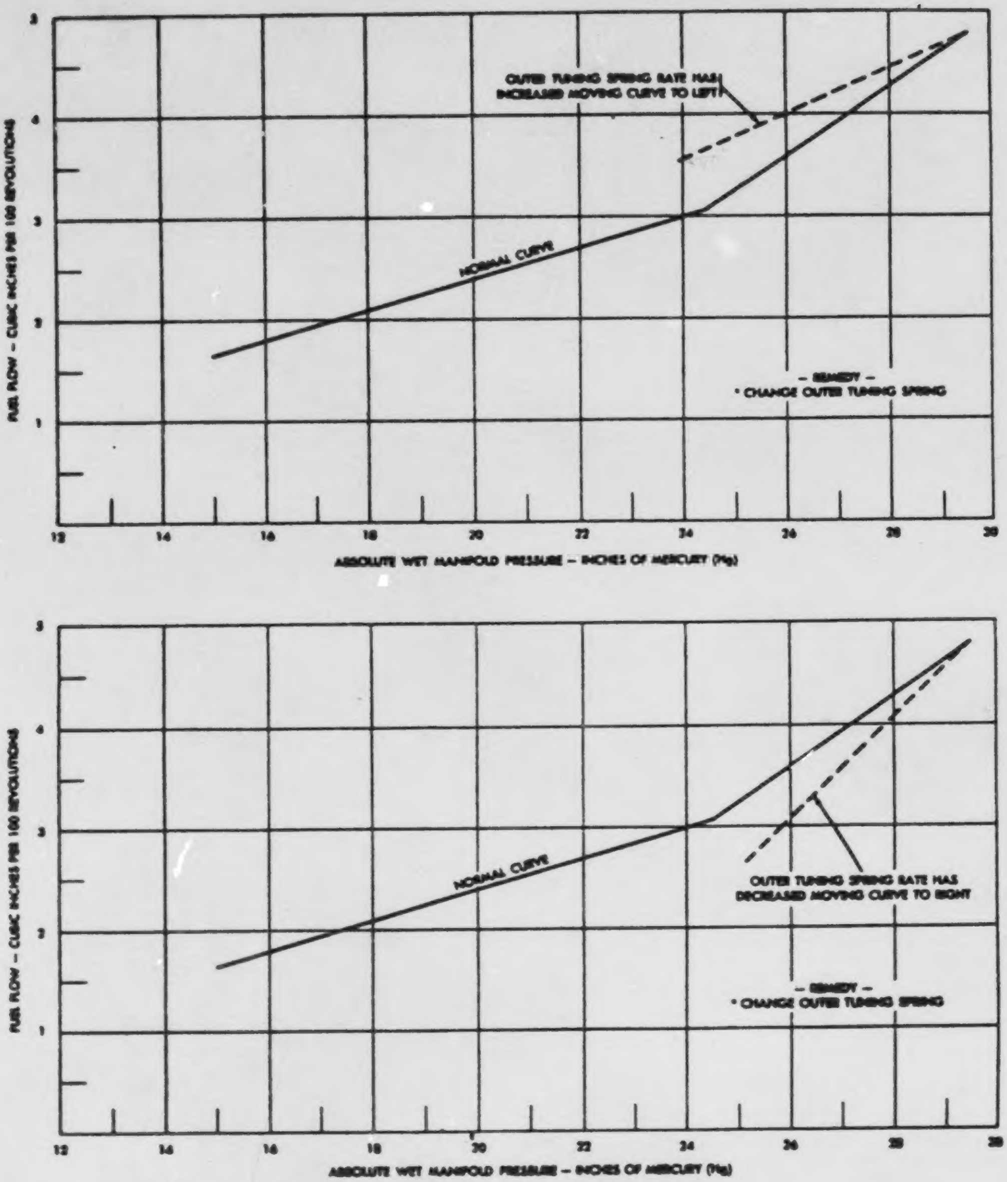

A—CAPSULE ASSY.—[illegible]
B—CAPSULE "O" RING PREFORMED PACKING—[illegible]
C—1/8-IN. HEX-HD PIPE PLUG—88044-AN932-1
D—BOTTOM CAPSULE ADJUSTMENT NUT—[illegible]
E—CAPSULE CROSS-PIN—77932-570134
F—TOP CAPSULE ADJUSTMENT NUT—[illegible]
G—METERING HD HOUSING W STUDS—77932-570737
H—LOCKING WIRE—0.032 DIA BR
J—NO. 10 INT-TEETH LOCK WASHER—88044-AN936-A10
K—CAPILLARY TUBE CLAMP—[illegible]
L—NO. 10 SCREW—[illegible]
M—CAPILLARY TUBE ASSY W TEMPERATURE BULB ASSY-NO NUMBER

Figure 7-6. Original metering head assembly—exploded view.


RA PD 32666C

A—Pump main body, w/parts—partial assembly
B—Inner tuning spring shim
C—Outer tuning spring
D—Inner tuning spring
E—Sandwich piece gasket
F—Sandwich piece assembly
G—Metering head gasket
H—Metering head assembly
J—Capsule adjustment cover assembly
K—No. 8 lockwasher
L—No. 8 x 3/16-inch fillister-head screw
M—Locking wire 0.032-inch dia. brass
N—Lead seal
P—No. 10 washer
Q—No. 10 castle nut

Figure 7-7. Metering head and sandwich piece assemblies—partially exploded view.



* NOTE: WHEN OUTER TUNING SPRING RATE IS INCREASED OR DECREASED THE LOWER LEG OF THE CURVE WILL BE INFLUENCED SINCE THE LOWER LEG IS A FUNCTION OF THE COMBINED RATES OF THE INNER AND OUTER TUNING SPRINGS.

Figure 7-8. Effects of outer tuning spring rate on fuel flow calibration curve.

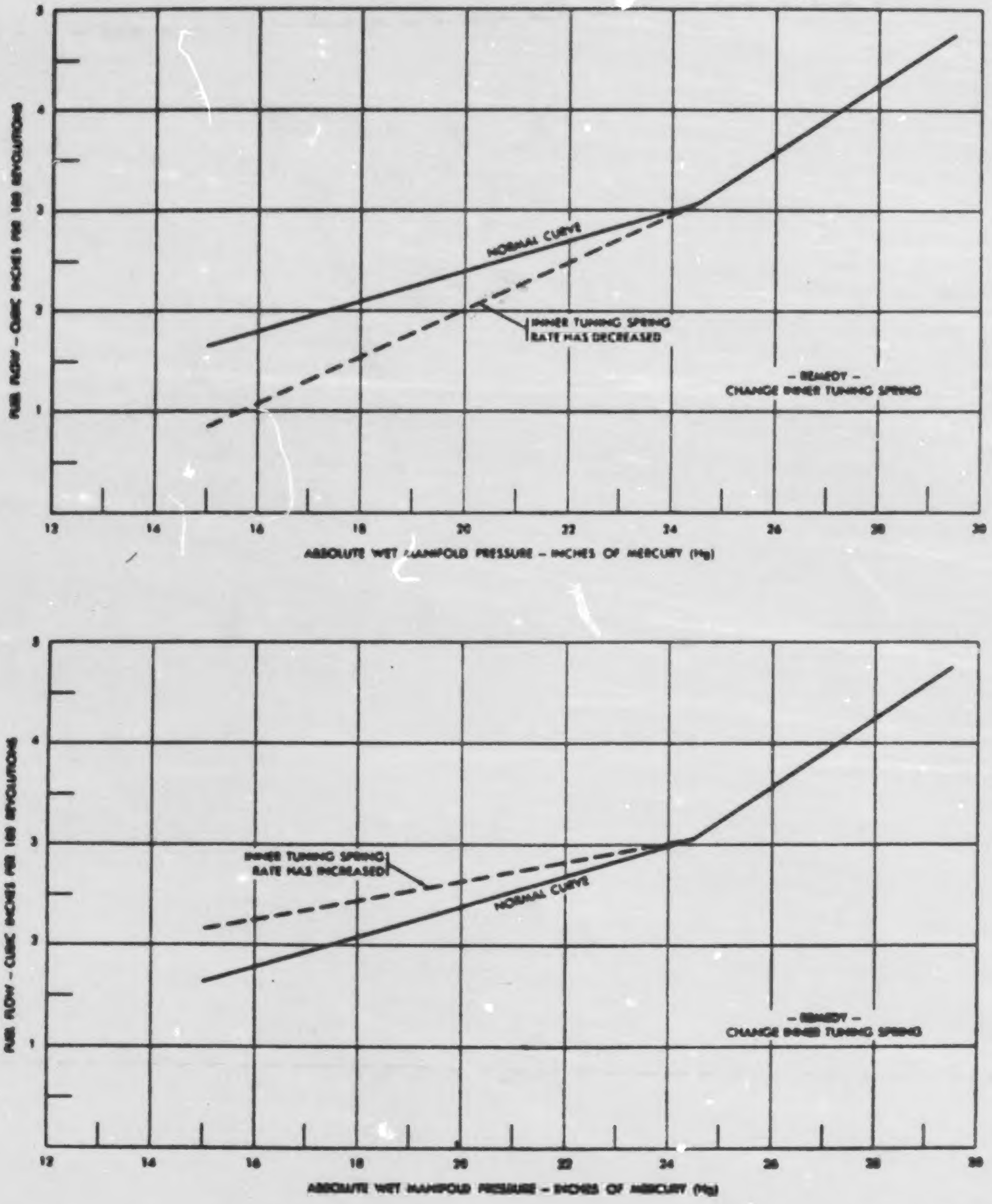


Figure 7-9. Effects of inner tuning spring rate on fuel flow calibration curve.

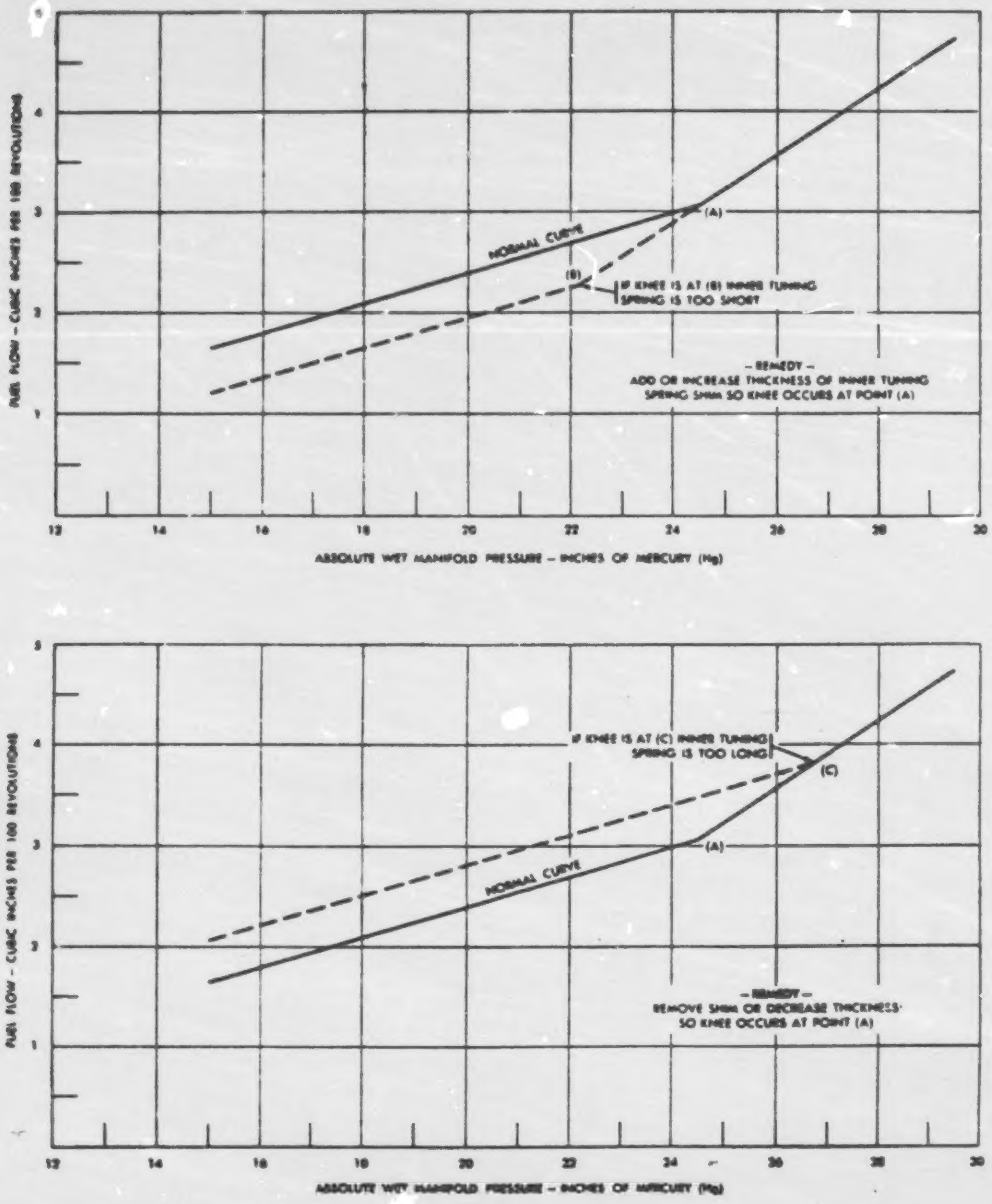


Figure 7-10. Effects of inner tuning spring shim thickness on fuel flow calibration curve.

(b) Turn off main drive switch, heater switch, and auxiliary motor switch in this sequence.

(c) When pump is cool enough to handle, disconnect all lines and remove from test stand.

7-7. CALIBRATION OF SIMMONDS INJECTOR PUMPS USING TEST STAND 4910-817-7431.

a. **Adapter and bracket.** Install 1/8-in pipe by 3/8-in flare fittings in tapped holes in adapter. Bolt adapter to mounting bracket, using capscrews, washers, and hex nuts provided, with flare fittings on the bottom between the feet of the mounting bracket. Place assembled bracket and adapter on mounting rails with adapter studs toward test stand operator. Thread stud on clamp bar into hole on bottom of bracket between mounting rails. Swing clamp bar across underside of mounting rails and tighten hand knob. In using test stand for first time install a pump gasket on the adapter. Be sure gasket does not cover servo oil holes on adapter or pump. Slide injection pump, with fuel vent up, onto adapter studs. Rotate adapter coupling to mesh male pump spline with female adapter spline. Use washers and hex nuts provided to hold pump to adapter. Place tooth coupling on adapter coupling. Loosen hand knob and slide bracket toward test stand drive coupling. Aline teeth of coupling and push together. Back off bracket one-sixteenth inch to provide a floating coupling between test stand and adapter.

b. **Hose connections.**

(1) **Lube oil lines.** Connect hose from outlet marked "LUBE PRESSURE" to left fitting on bottom of adapter. Connect another hose for oil return from bottom right fitting on adapter to manifold outlet marked "LUBE RETURN."

(2) **Fuel lines.** Connect hose from manifold outlet stamped "FUEL PRESSURE" to one of the pump's fuel inlet ports. Install hose from pump vent opening to manifold outlet stamped "FUEL RETURN." Do not remove the vent fitting from the pump as it contains an orifice necessary to maintain internal pump pressure. Be sure cap is tight on manifold outlet marked "PRIMER OUTLET."

(3) **Manifold lines.**

(a) Pumps from unsupercharged engines - connect hose from front panel outlet marked "MANIFOLD INLET" to manifold inlet on fuel pump.

(b) Pumps from supercharged engines:

1. Connect hose from front panel outlet marked "MANIFOLD INLET" to port marked "INT MANIFOLD" on idle control device.

2. Plug port marked "THROTTLE HOUSING" on idle control device.

3. Connect hose from panel outlet marked "SUPERCHARGER INLET" to port marked "MET PR" (metering pressure) on capsule housing.

4. Plug port marked "ACCEL PUMP" on capsule housing.

(4) Nozzles and lines. Install nozzle adapters in accumulators. Push nozzles through nozzle adapters and tighten, using 1-3/8-in wrenches provided with test stand. Connect nozzles to fabric-covered connecting hoses. Outlet ports on pump are marked "A, B, C," etc. Connect hose from nozzle fartherest from test stand drive shaft to port A. Connect next nozzle to port B, etc, working from left to right.

c. **Temperature sensing bulb.** Push temperature sensing bulb, if pump is so equipped, into sensing bulb chamber.

d. **Heating test stand.** Turn on auxiliary motor switch to start fuel, lube oil, and air pumps. Oil pressure should always be at least 10 PSI higher than fuel pressure; if not, immediately increase servo oil pressure with servo oil regulator. Turn on lube oil heater switch to energize lube oil heaters. Be sure bulb temperature is 100° F and lube oil temperature is 165° F, or at temperature stated in pump manufacturer's manual, before beginning tests. Injection pump will be hot to the touch when at operating temperatures. When bulb chamber and lube oil reach desired temperatures, increase lube oil pressure to 60 PSI, unless otherwise stated in pump calibration curve, with the lube oil regulator. Set fuel pressure at 20 PSI with fuel pressure regulator. Some variation of lube oil and fuel pressure will be noted as pump calibration is checked; this is normal and need not be compensated.

e. **Metering valve calibration procedure.** This test is performed only on injection pumps from supercharged engines. Metering valve is checked for proper operation by measuring the pressure differential in the bellows chamber while increasing manifold pressure.

f. **Injection pump at operating temperatures and pressures.**

Note. - Pump is not running when making this test.

(1) Set vacuum pressure selector valve to "PRESSURE."

(2) Set manifold pressure capsule pressure valve to "MAN PRESS."

(3) Refer to metering valve calibration curve (fig 7-11) for pump model under test. Vertical figures at left side of graph represent manifold pressure drop. Figures at bottom of graph are the manifold pressure (test gage) values at which test will be conducted. Figures at bottom of graph are inches Hg above atmospheric pressure; test stand manifold pressure gage reads in inches Hg absolute pressure; therefore, for example, 6 inches Hg on calibrating curve equals 39 in Hg on gage; 7 on curve equals 38 on gage, etc.

(4) Use manifold pressure regulator to set manifold pressure gage to 39 in Hg. In setting manifold pressure gage with either the manifold vacuum or manifold pressure regulators, use care not to overshoot required setting. For greatest accuracy, it is desirable to take up any play in gage by moving pointer steadily in one direction - either up or down the scale - through a calibration test.

(5) Turn manifold pressure capsule pressure valve to "capsule pressure." Manifold pressure gage reading should remain at 38 in Hg.

(6) Return manifold pressure capsule valve to "manifold pressure."

(7) Use manifold pressure regulator to set manifold pressure gage to 40 in Hg.

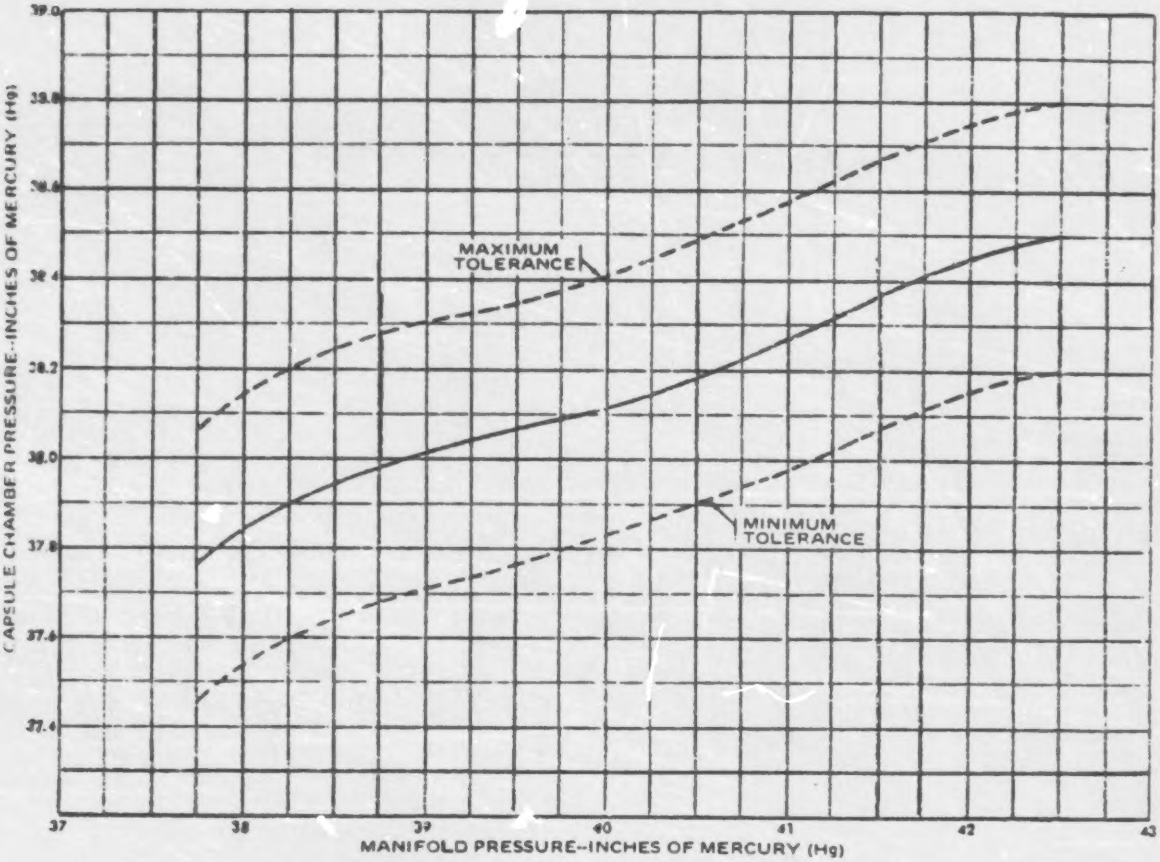


Figure 7-11. Calibration chart for metering valve assembly used on fuel injector pump 794093.

(8) Turn manifold pressure capsule pressure valve to "capsule pressure." Manifold pressure gage reading will fall slightly to indicate manifold pressure drop. (For example: 39 -in Hg gage reading minus 1/4-in Hg manifold pressure drop equals 38-1/4-in gage reading.)

(9) Repeat steps (6) and (8) above, changing manifold pressure gage settings as given on bottom of figure 7-11. Two readings should be taken at each test point on the metering valve calibration curve. Begin first test run at 39 in Hg and progress in sequence to 42-in Hg manifold pressure. Repeat test, starting at 42 in Hg, and work down in sequence to 39-in Hg manifold pressure. This is general procedure for making a metering valve check. Refer to the metering valve calibration curve for the pump under test for specific valves to be used for that pump.

g. Adjustment of fuel metering device.

(1) Remove lock-wire and adjusting screw cover.

(2) Hold adjusting screw with screwdriver and loosen locknut.

(3) Turn adjusting screw clockwise to DECREASE pressure drop; counterclockwise to INCREASE pressure drop.

(4) Turn adjusting screw until proper curve is achieved.

(5) Hold adjusting screw with screwdriver and tighten locknut.

(6) Replace screw cover and lock-wire.

h. **Starting main drive.** Turn shifting crank to HIGH position and turn on main drive switch when temperatures and pressures are at correct levels. Do not increase test stand speed. Set count selector switch to 500 and operate count pushbutton to fill delivery lines and wet inner surfaces of burettes for greater accuracy in reading. When count is complete, push dumping lever in lock in drain position until calibration runs. If no fuel flows into burettes, check for proper rotation of test stand drive coupling. Use fast pushbutton to increase test stand speed to 1,800 RPM for all calibration runs, unless otherwise noted in pump manufacturer's manual.

i. **Fuel delivery test procedure.** Fuel delivery is checked by measuring fuel flow while increasing manifold pressure from minimum to maximum, then reversing procedure and measuring flow while decreasing manifold pressure. It is optional whether test is begun at minimum or maximum manifold pressure. A short table of fuel flows for various Simmonds application is shown in tables 7-1 and 7-2.

(1) Fuel and lube oil pressures and temperatures for the pump are the same as for metering valve calibration. Test stand speed is 1,800 RPM, unless otherwise noted in manufacturer's manual.

(2) Set manifold pressure capsule pressure valve to "MAN PRESS" for entire test run.

(3) Turn vacuum pressure selector valve to "VACUUM."

(4) Refer to fuel flow calibration table for pump model under test and use vacuum regulator valve to set manifold pressure gage to lowest value on table.

(5) With dumping lever in FILL position, push count button to collect fuel.

(6) When count is complete, record individual burette levels and their sum.

(7) Repeat steps (4), (5), and (6) above at suitable increases of manifold pressure to highest figure given at left of fuel calibration table. Where manifold pressure is higher than atmospheric pressure, turn vacuum pressure selector valve to "PRESSURE" and use pressure regulator valve to set manifold pressure gage.

(8) When highest MAP on fuel curve is reached, repeat steps (4), (5), and (6) above at suitable DECREASES in MAP down to the minimum shown on fuel table. Where MAP falls below atmospheric pressure, turn vacuum pressure selector valve to "VACUUM" and use vacuum regulator valve to set manifold pressure gage.

(9) At end of second test run, compare average fuel data collected with fuel flow calibration table and determine whether or not pump tested falls within acceptable limits.

Table 7-1. Fuel Flow Limits - Cubic Centimeters 500 Pump Revolutions.

AOI-402-5

MAP	60°F.	70°F.	80°F.	90°F.	100°F.	110°F.	120°F.	130°F.	140°F.
14	64-68	63-67	63-67	62-66	62-66	61-65	61-65	61-64	60-64
17	77-81	76-80	76-80	75-80	74-79	74-78	73-78	73-77	72-77
20	88-94	87-93	87-93	87-92	86-92	86-91	85-91	85-90	85-90
24	117-124	116-123	114-122	113-121	111-118	110-117	108-116	107-114	106-113
26	139-148	137-146	136-145	135-144	133-141	132-140	131-139	130-138	128-136
28	161-171	160-170	159-168	157-167	156-165	154-163	153-162	152-162	151-161

AOI-1195-5

14	179-190	178-189	176-187	173-184	172-183	170-180	167-178	166-177	164-174
18	226-240	225-239	223-237	221-235	220-233	217-231	215-228	214-227	211-224
22	274-291	273-290	271-287	268-285	267-284	264-281	263-279	261-278	259-275
26	359-381	356-378	351-371	344-365	341-362	335-356	330-350	327-347	321-341
28	415-441	414-440	406-432	402-426	399-423	394-418	388-412	386-410	379-403
30	473-503	471-501	466-494	460-488	457-485	452-480	445-473	443-471	437-465

AOI-268-1

14	93-99	91-97	90-96	89-95	88-94	87-93	86-92	85-91	84-90
18	123-131	122-129	121-128	120-127	119-126	118-125	117-124	115-123	114-122
22	154-164	152-162	152-161	151-160	150-159	149-158	148-157	146-155	145-154
26	201-213	197-210	196-208	194-206	191-203	190-202	188-200	187-199	186-197
28	233-247	229-243	227-241	226-240	223-237	221-235	220-233	216-230	215-228
30	264-280	262-278	260-276	258-274	255-271	253-269	251-267	249-264	247-263

Table 7-2. Fuel Flow Limits - Cubic Centimeters 500 Pump Revolutions.

AVSI-1790-6

MAP	60°F.	70°F.	80°F.	90°F.	100°F.	110°F.	120°F.	130°F.	140°F.
14	143-152	141-150	139-148	135-145	133-142	131-139	127-136	125-134	123-131
18	194-206	191-202	189-201	186-198	184-195	182-193	177-188	174-185	172-183
24	269-384	267-382	264-278	262-277	259-274	257-272	253-268	250-266	248-362
32	440-468	432-459	426-452	418-443	412-435	404-429	398-418	389-411	382-404
36	579-615	574-607	565-598	557-590	550-584	544-577	533-565	528-558	517-551
40	717-763	711-754	702-747	697-740	690-733	683-725	673-713	665-706	657-699

AVI-1790-8

14	113-122	112-121	110-119	107-116	106-115	104-113	103-111	102-110	99-107
18	157-170	156-169	154-166	152-164	151-162	149-160	147-158	145-156	143-154
22	203-217	202-216	199-213	197-211	196-210	194-208	192-205	191-204	188-202
26	269-289	268-285	262-280	257-275	254-271	250-266	244-261	241-258	236-252
28	322-344	319-341	315-336	309-330	306-327	301-321	295-316	292-313	288-308
30	374-398	372-396	366-391	360-387	358-382	354-377	348-371	345-369	340-364

AOSI-895-5

14	122-140	127-138	123-134	121-132	118-129	115-125	113-123	110-119	107-117
18	183-196	180-193	178-189	175-186	172-183	168-181	166-177	164-174	161-172
24	263-279	259-277	255-274	252-270	251-267	247-264	246-262	242-259	240-256
32	451-481	446-476	439-466	434-460	427-454	422-447	416-442	410-435	404-430
36	564-602	561-596	553-588	548-582	542-576	536-570	530-565	524-557	518-550
40	675-725	673-718	666-710	660-704	655-697	650-690	644-685	639-679	634-674

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j. **Procedure for shutting down test stand.** When testing is completed, use slow push-button to reduce speed to lowest point. Turn off main drive switch, heater switch, and auxiliary motor switch, in that order. When pump is cool enough to handle, disconnect fuel, lube oil, vacuum, and nozzle lines. Plug all openings to prevent dirt entering pump and remove pump from adapter.

k. **Procedure for nozzle testing.** Install nozzle checking device.

l. **Checking nozzle cracking pressure.**

(1) Operate hand pump to purge line of entrapped air.

(2) When nozzle delivers fuel, insert through rubber stopper into spray chamber.

(3) Turn knob on pressure gage and reset lazy hand against gage pointer.

(4) Operate hand pump using slow, steady strokes. Stop pumping at first drop of pressure indicated on gage.

(5) Read cracking pressure shown by lazy hand. Nozzles 570010 and 570023 have a cracking pressure between 50 and 70 PSI.

m. **Spray pattern.**

(1) Operate hand pump with short, rapid strokes and maintain a pressure 10 to 15 PSI above cracking pressure.

(2) Observe nozzle spray pattern. Spray cone should be finely atomized and form a full cone of approximately 90°.

n. **Nozzle dribble.**

(1) Operate hand pump with slow, steady strokes to maintain a pressure of 40 PSI.

(2) Nozzle in serviceable condition should not leak more than one drop per minute. Leakage in excess of this amount indicates dirt under pintle seat or erosion of pintle or body. If nozzle dribbles, purge nozzle with fuel by making several rapid strokes with hand pump. This will dislodge dirt under seat. After purging with fuel, recheck nozzle for dribble.

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SECTION VIII. FUEL SYSTEM, AVDS 1790-2 ENGINE, M60 VEHICLE

8-1. GENERAL. The intake manifold heater system incorporates two heater bodies, two TCN ignition coils, two solenoid valves, a 90-PSI relief valve, and the associated plumbing and electrical wiring. As shown in figure 8-1, operation of the vehicle hand purge pump must first produce a minimum of 90 PSI on the outlet of the pump and the inlet to the fuel supply solenoid valve. When the valve is opened by operation of the electrical switch on the hand pump, the fuel is pumped through the primer filter to the two split flow nozzles mounted in the heater bodies. The return fuel from the nozzles passes through the return solenoid to the top of the fuel tank in the vehicle. Operation of the heater control switch on the hand pump opens both solenoid valves and actuates both ignition units simultaneously. Any excess fuel pumped by the operator passes through the 90-PSI relief valve and purges air pockets from the main fuel system, while maintaining 90-PSI fuel pressure to the heater system and boosting the pressure to the injection pump. When the hand pump is operated with the heater system not operating, all output from the hand pump passes through the 90-PSI relief valve and purges vapor from the main fuel system in the normal manner. In either case, the hand pump provides a boost pressure to the injection pump.

8-2. FUEL SYSTEM - BASIC DESCRIPTION.

a. **Basic parts.** The fuel system is composed of two interconnected fuel tanks with an electric fuel pump mounted in each tank, a check valve and tee, a fuel supply on-off valve, a primary filter, a vane-type fuel transfer pump, two secondary fuel filters, a secondary fuel injector booster pump, twelve fuel injector nozzles, a purge pump located in the driver's compartment, a manifold flame heater for cold-weather starting, a crew compartment heater, and a heater electric fuel pump. For emergency fuel tank isolation, there is a 3-inch butterfly isolation valve located in the fuel tank interconnector hose and a three-port return selector and isolation valve located in the main engine fuel return line. A fuel transfer pump, fuel tank condensate removal system, and four fuel lines for off-vehicle engine operations are provided in the vehicle OVE.

b. **Component data for fuel tanks.**

(1) Total capacity - 385 gallons.

(2) Left tank - 189 gallons.

(3) Right tank - 196 gallons.

(4) Construction - riveted and welded aluminum plate and extrusions.

c. **Electric fuel pump description.** The pump is manufactured by the Tokheim Corporation and is the impeller type. The unit is an electrically driven centrifugal pump which is submerged in the fuel tank. The motor requires 24 VDC (negative ground) with an amperage draw ranging between 0.8 amperes and 1.4 amperes. The electric motor, which is hermetically sealed in a stainless steel housing, rotates an 8-pole disk magnet, thereby transmitting force through the stainless steel bulkhead. This force rotates a magnet on the impeller shaft, and the impeller "pushes" the fuel forward to the transfer pump at constant pressure, constant flow. The motor shaft and impeller shaft bearings are carbon for longer life and require no lubrication. Lift expectancy of the entire unit is 2,000 hours when operating in a temperature range of -65° to +165° F.

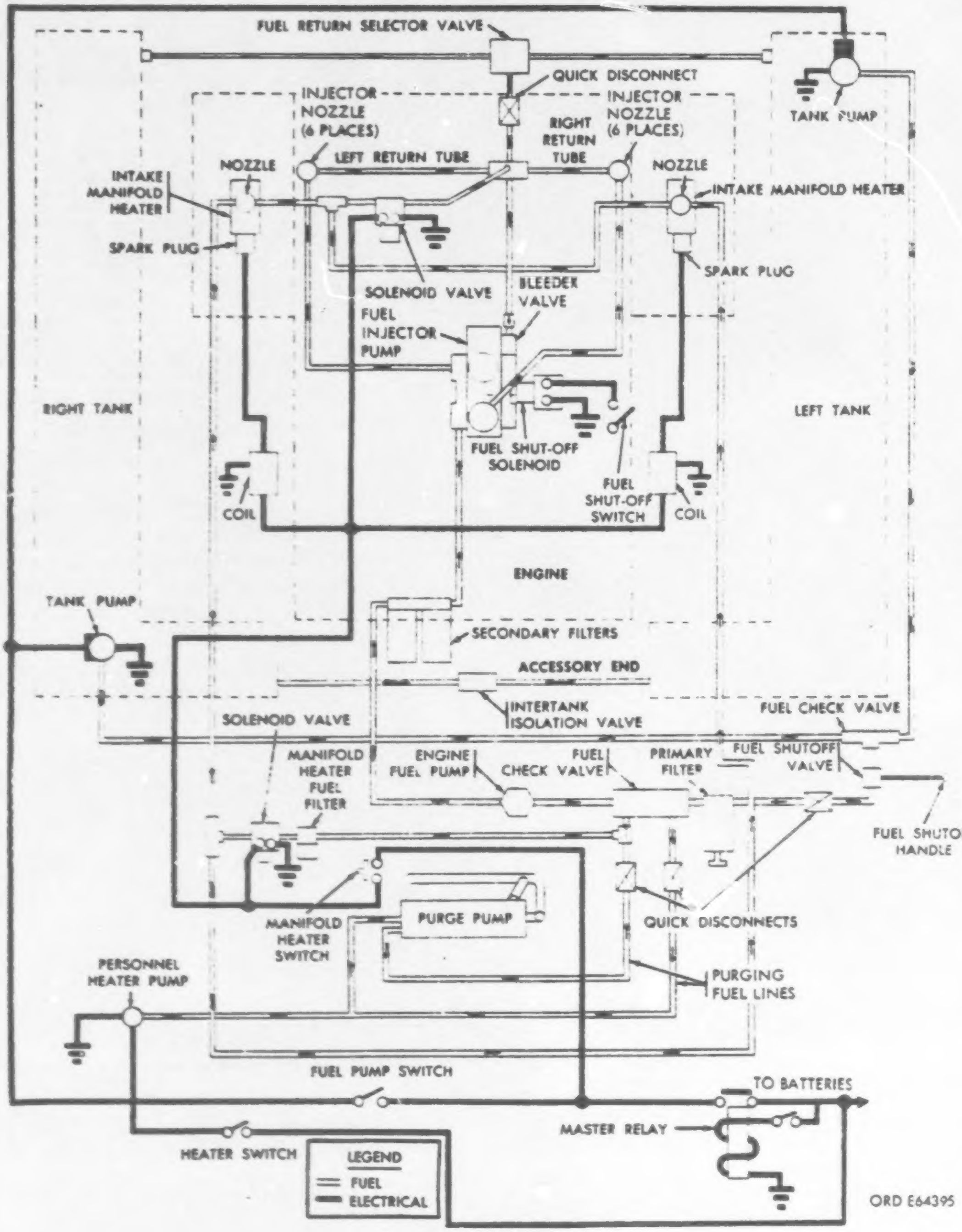

FUEL RETURN SELECTOR VALVE
QUICK DISCONNECT
INJECTOR NOZZLE (6 PLACES)
RIGHT RETURN TUBE
INJECTOR NOZZLE (6 PLACES)
TANK PUMP
LEFT RETURN TUBE
NOZZLE
NOZZLE
INTAKE MANIFOLD HEATER
INTAKE MANIFOLD HEATER
SPARK PLUG
SPARK PLUG
SOLENOID VALVE
BLEEDER VALVE
FUEL INJECTOR PUMP
RIGHT TANK
LEFT TANK
FUEL SHUT-OFF SOLENOID
FUEL SHUT-OFF SWITCH
COIL
COIL
ENGINE
TANK PUMP
SECONDARY FILTERS
ACCESSORY END
INTERTANK ISOLATION VALVE
SOLENOID VALVE
FUEL CHECK VALVE
MANIFOLD HEATER FUEL FILTER
ENGINE FUEL PUMP
FUEL CHECK VALVE
PRIMARY FILTER
FUEL SHUTOFF VALVE
FUEL SHUTOFF HANDLE
PURGE PUMP
MANIFOLD HEATER SWITCH
QUICK DISCONNECTS
PERSONNEL HEATER PUMP
PURGING FUEL LINES
FUEL PUMP SWITCH
TO BATTERIES
MASTER RELAY
HEATER SWITCH
LEGEND
FUEL
ELECTRICAL
ORD E64395

Figure 8-1. Tank fuel system - schematic diagram.

d. Data for system components.

- (1) Intertank isolation valve.
    - (a) Type - 3-in butterfly.
    - (b) Rated flow - 50 GPM.
    - (c) Pressure: operating - 4.5 PSI.
- (2) Fuel return selector valve.
    - (a) Type - ball rotor.
    - (b) Rated flow - 3.7 GPM, 220 GPH.
    - (c) Pressure: operating - 30 PSI.
- (3) Fuel tank electrical fuel pumps.
    - (a) Type - impeller (indirect drive, dry motor, hermetically sealed, magnetic coupling).
    - (b) Rated capacity - 220 GPH at 3.75 PSI (M60A1).
- (4) Check valve.
    - (a) Type - double swing-check.
    - (b) Operating pressure - 50 PSI.
    - (c) Opening pressure - 0.2 PSI max.
- (5) Fuel shutoff valve.
    - (a) Type - ball rotor.
    - (b) Rated flow - 3.7 GPM, 220 GPH.
    - (c) Pressure: operating (maximum) - 30 PSI.
- (6) Primary fuel filter (cleanable element).
- (7) Secondary fuel filter (disposable element).
- (8) Purge pump.
    - (a) Type - double acting manual.
    - (b) Pressure developed - over 200 PSI (when pumping fuel).
    - (c) Vacuum developed - 17 in mercury min (when pumping air).

(9) **Manifold heater spark plug.**

(a) **Manufacturer and model** - Scintilla Div, Bendix Aviation Corp, part No 10-324058; or Champion Spark Plug Co, part No ED-89D with A676 gasket.

(b) **Gap setting** - 0.094-0.114.

8-3. OPERATION OF THE INJECTION SYSTEM.

a. The pump consists of two individual 6-cylinder, single-plunger, distributor-type injector pumps integrated into a single 12-cylinder unit by means of a tandem arrangement. With this arrangement, the distributor head of each individual pump serves one particular bank of the engine. The pump is driven at engine speed and is located in the engine vee. A hydraulic advance unit is incorporated in the accessory drive housing of the engine to automatically provide a gradual 11° advance of injection timing over the speed range.

b. All of the fuel injection lines are the same length and are made of 0.250-inch OD, 0.84-inch ID, soft annealed tubing. Hole-type nozzles are used with eight orifices for even fuel distribution in the open-type combustion chambers.

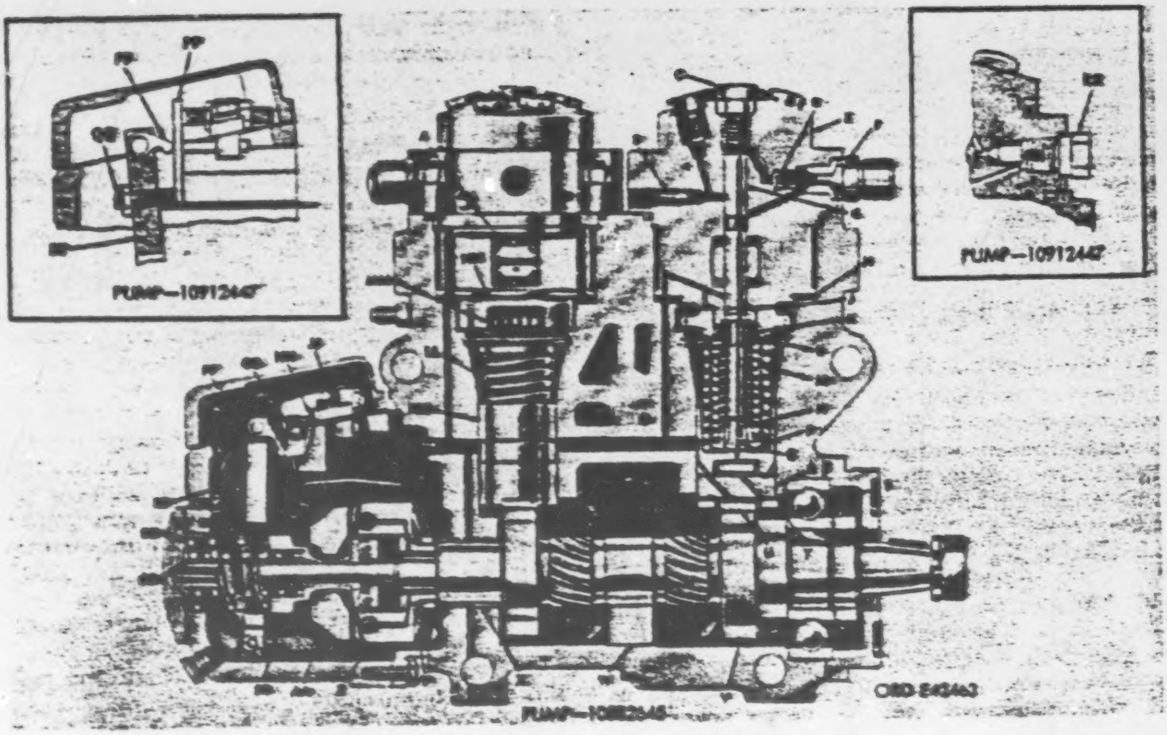
c. Electric fuel pumps, one in each fuel tank, provide fuel at constant low pressure to an engine-driven fuel supply pump which supplies fuel under higher pressure to the injection pump. The pump then delivers accurately metered quantities of fuel under high pressure to the spray nozzles, through which the fuel is injected into engine cylinders, at a definite timing in relation to the engine firing cycle and within the required injection period.

Note. - The description of operation given below is concerned with the PSB-type pump in general. The PSB 12BT-110 GH-4900A1 injection pump used on the AVDS 1790-2 engine is a larger version. Operating principles and functioning within the hydraulic heads are the same. The drive for plunger reciprocation and rotation for distribution are essentially the same, except the PSB 12BT has two three-lobe cams and two quill shafts and the PSB 6A has one quill shaft and one three-lobe cam.

8-4. OPERATION OF THE FUEL INJECTOR PUMP - AMERICAN BOSCH TYPE PSB.

Individual heads insure uniformity of fuel delivery. When two are used, they must be balanced for same flow. This is done by means of an adjustable linkage connecting the two control unit levers. The cast aluminum housing, which supports the camshaft and quill shaft drive, is recessed to accept the two hydraulic heads and is also flanged for mounting the governor. It has a vertical plane on the rear for mounting to the engine. The governor of the mechanical-centrifugal, variable speed, internal spring type is driven directly from the camshaft. This model incorporates a fuel-limiting device which momentarily prevents excessive fuel delivery at intermediate settings. A friction clutch is incorporated in the governor drive system which is used for protection in quick accelerations.

Note. - For advance unit mechanism, see figure 8-3.



A - Plunger sleeve
B - Fuel passage closure plug
C - Plunger bore screw
D - Fuel delivery valve
E - Hydraulic head
F - Delivery valve cap screw assy (pump - 10882645)
G - Fuel plunger
H - Hydraulic head spacer
J - Drive gear thrust washer
K - Plunger guide
L - Plunger spring upper seat
M - Plunger return spring
N - Plunger lock
P - Plunger spring lower seat
Q - Plunger button
R - Tappet roller pin
S - Camshaft ball bearing
T - Tappet guide assy
U - Roller assy
V - Camshaft
W - Camshaft center bearing (pump - 10882645)
X - Camshaft sleeve bearing
Y - Spring disk
Z - Friction drive spider
AA - Governor weight assy
BB - Sleeve assy
CC - Governor inner spring
DD - Governor outer spring
EE - Fulcrum lever assy
FF - Smoke limit cam
GG - Adjustable stop plate (pump - 10882645)
HH - Torque control stop plate (pump - 10882645)
JJ - Stop plate bridge
KK - Tappet assy
LL - Tappet spring
MM - Plunger drive spur gear
NN - Drive gear retainer
PP - Stop plate (pump - 10912447)
QQ - Droop adjustment screw (pump - 10912447)
RR - Delivery valve cap screw (plug type) (modified pump - 10882645 nnd pump - 10912447)

Figure 8-2. Fuel injection metering pump assembly - sectional view.

a. **Pumping.** Fuel enters the pump from the supply system through the inlet connection and fills, through two intake ports in the upper bore, that portion of the barrel cavity between the top of the plunger and the front of the delivery valve when the plunger is at the bottom of its stroke. As the rotating plunger moves upward in its stroke under cam action, it soon passes and closes the intake ports, trapping and pressurizing the fuel and opening the spring-loaded delivery valve. As the plunger continues its upward stroke, the fuel that is forced through the delivery valve is conveyed through the communicating ducts to the annulus in the plunger, through the vertical distributing slot on the plunger and to that outlet duct with which the distributing slot is then registering as the plunger rotates. After sufficient upward movement of the plunger, the spill port passes the edge of the control sleeve and the fuel under pressure escapes down the vertical hole in the center of the plunger and into the sump surrounding the control sleeve, which is at supply pressure. With collapse of the pressure in front, the delivery valve then closes, during which action the piston portion of the valve blocks the passage before the valve reaches its seat and thus performs its function of reducing the residual pressure in the discharge system. This is the end of the pumping cycle.

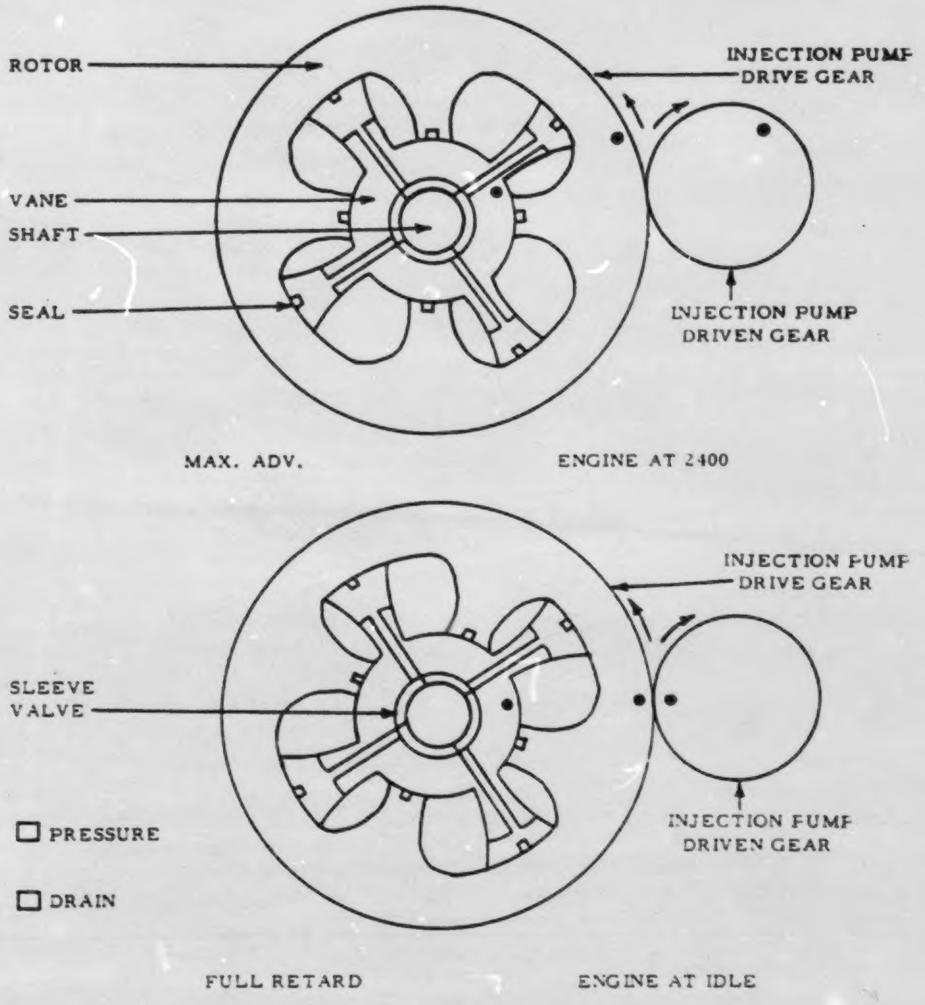

ROTOR
INJECTION PUMP DRIVE GEAR
VANE
SHAFT
SEAL
INJECTION PUMP DRIVEN GEAR
MAX. ADV.
ENGINE AT 2400
INJECTION PUMP DRIVE GEAR
SLEEVE VALVE
INJECTION PUMP DRIVEN GEAR
☐ PRESSURE
☐ DRAIN
FULL RETARD
ENGINE AT IDLE

Figure 8-3. Hydraulic advance unit—principles of operation AVDS 1790-2 engine.

b. **Metering and control.** Quantity of fuel delivered per stroke is governed by variation of the position of the control sleeve in relation to the fixed port closing position (the point at which the top of the plunger covers the intake ports); as the spill port on the plunger breaks over the top edge of the control sleeve, pumping pressure is relieved down through the center hole of the plunger, out into the sump surrounding the control sleeve, and fuel delivery terminates despite the continued upward movement of the plunger.

(1) If the control sleeve position is raised, the spill port on the plunger remains covered by the sleeve until relatively late in the plunger stroke; hence, the effective stroke of the plunger is longer and more fuel is delivered. If the control sleeve position is lowered, the spill port on the plunger is uncovered by the sleeve relatively sooner in the plunger stroke; hence, the effective stroke of the plunger is shorter and less fuel is delivered.

(2) When the control sleeve is lowered to its extreme point, the spill port on the plunger is uncovered by the top edge of the sleeve before the upper end of the plunger can cover the intake ports. Under this condition no pressure can be built up even after the ports are closed; hence, no fuel can be delivered. This is the shutoff position.

(3) It will be seen that upward movement of the control sleeve increases the quantity of fuel pumped per stroke and downward movement decreases the quantity of fuel pumped per stroke until the point of zero delivery is reached.

Note. - Figures 8-4 through 8-7 show the phases of pumping and metering.

c. **Delivery valve.** The delivery valve assembly, situated directly above the pumping chamber, assists the metering function by preventing irregular loss of fuel from the delivery side of the system to the supply side between pumping strokes. It consists of the valve proper, on which is a retraction piston; a tapered seat; the valve body, which receives the valve and has a corresponding tapered seat; and the valve spring. After the plunger on its upward stroke closes the intake ports, pressure is created. When this pressure overcomes the force of the spring holding the delivery valve on its tapered seat, the valve opens and fuel under pumping pressure flows through it and the distributing passages into the injection tubing. When the plunger continues its upward stroke and opens the spill port there is a sudden drop in fuel pressure in front of the delivery valve; the force of valve spring, combined with the high differential in pressure, acts to return the valve to its seat. As the valve starts into its bore the lower edge of its retraction piston enters the valve bore and blocks the passage. Further movement of the valve with its retraction piston increases the volume on the high pressure by the retraction piston movement (its displacement volume) and consequently reduces the residual pressure in the line. This lowered line pressure promotes rapid closing of the injection nozzle valve and diminishes the effects of the hydraulic pressure waves that exist in the tubing between injections, minimizing the possibility of nozzle valve reopening prior to the next regular delivery cycle.

d. **Internal spring type governor.** The variable speed, mechanical-centrifugal governor is attached to the pump and driven through it. The governor shaft has two forged flyweights attached to it through fulcrum pins in a spider. As speed is increased, the flyweights move away from the shaft. Fingers on the flyweights act against a thrust bearing on the sleeve to move the sleeve against the governor springs. The sleeve is connected to the fulcrum lever through pivot pins in the lever sliding in grooves in the sleeve, so that as the sleeve moves the lever moves. The lever is, in turn, connected through a linkage to the control sleeve in the hydraulic head to move the control sleeve correspondingly. As noted above, the position of the control sleeve determines the quantity of fuel delivered.

PUMPING AND METERING—PHASE I

PUMP, INJECTION, TYPE PSB 12BT

AVDS-1790-2 ENGINE

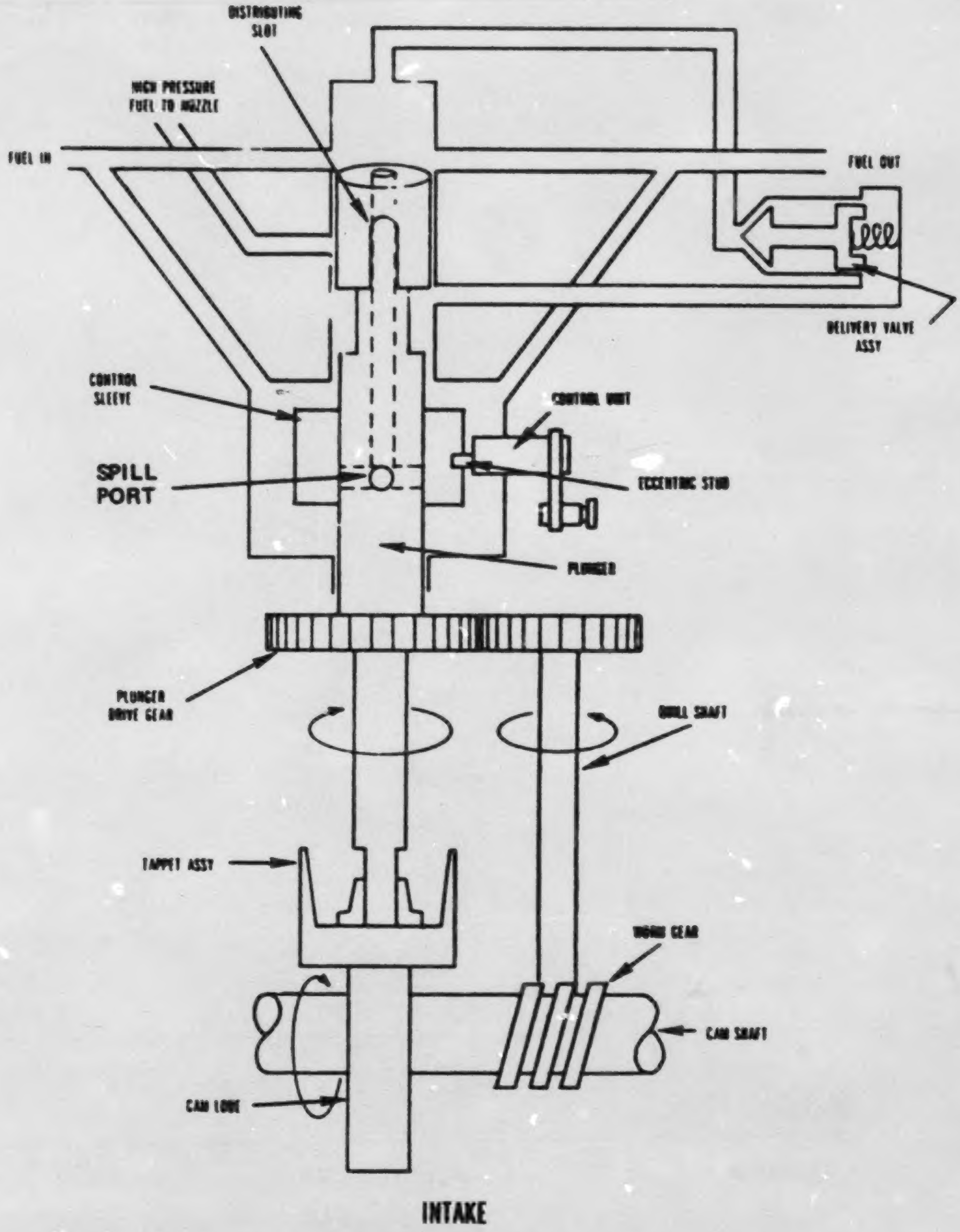
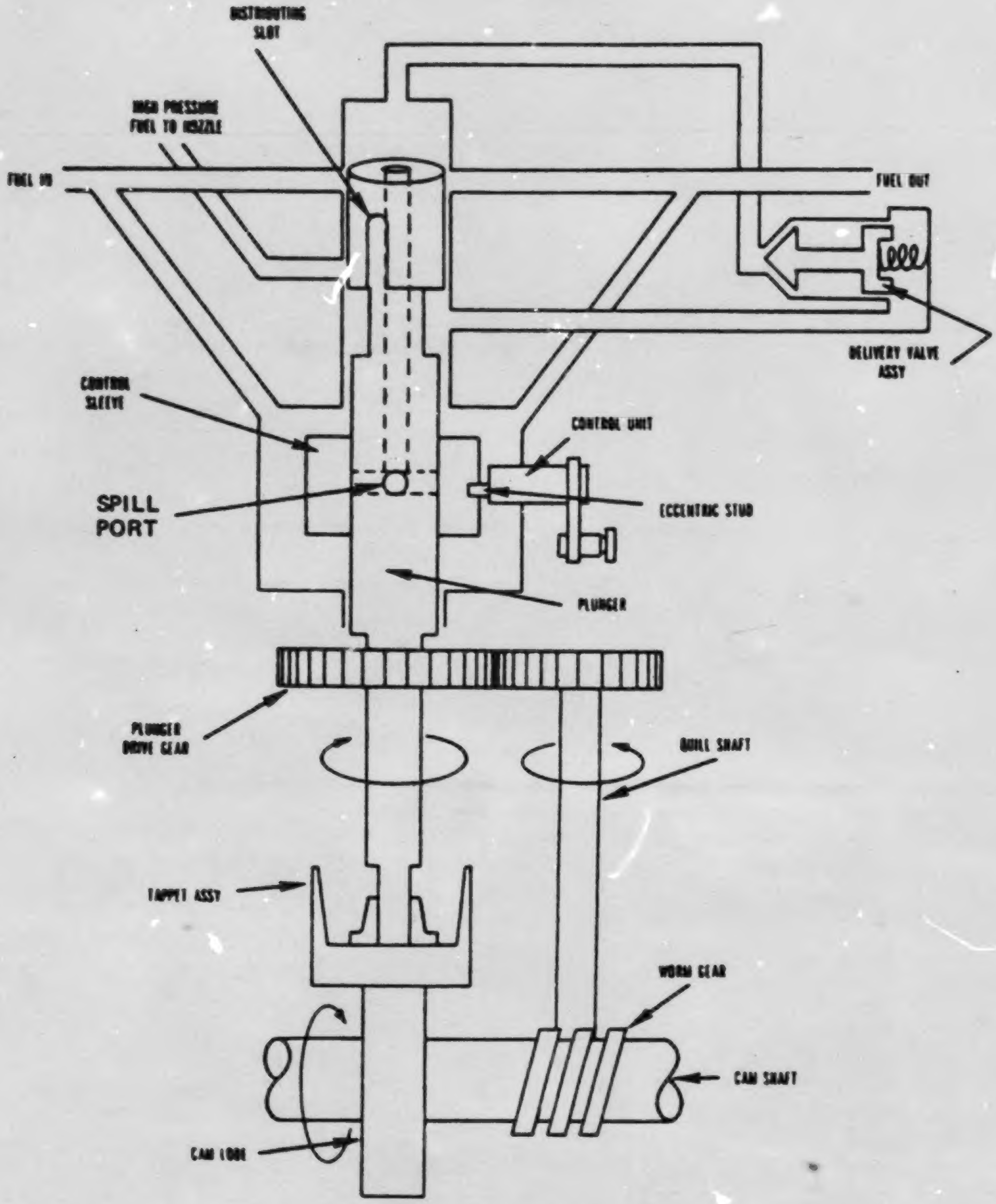

DISTRIBUTING SLOT
HIGH PRESSURE FUEL TO NOZZLE
FUEL IN
FUEL OUT
DELIVERY VALVE ASSY
CONTROL SLEEVE
CONTROL UNIT
SPILL PORT
ECCENTRIC STUD
PLUNGER
PLUNGER DRIVE GEAR
QUILL SHAFT
TAPPET ASSY
WORM GEAR
CAM SHAFT
CAM LOBE
INTAKE

Figure 8-4. Pumping and metering—phase I.

PUMPING AND METERING—PHASE II
PUMP, INJECTION, TYPE PSB 12BT
AVDS-1790-2 ENGINE


DISTRIBUTING SLOT
HIGH PRESSURE FUEL TO NOZZLE
FUEL IN
FUEL OUT
DELIVERY VALVE ASSY
CONTROL SLEEVE
CONTROL UNIT
SPILL PORT
ECCENTRIC STUD
PLUNGER
PLUNGER DRIVE GEAR
QUILL SHAFT
TAPPET ASSY
WORM GEAR
CAM SHAFT
CAM LOBE

BEGINNING OF DELIVERY

Figure 8-5. Pumping and metering—phase II.

PUMPING AND METERING—PHASE III

PUMP, INJECTION, TYPE PSB 12BT

AVDS-1790-2 ENGINE

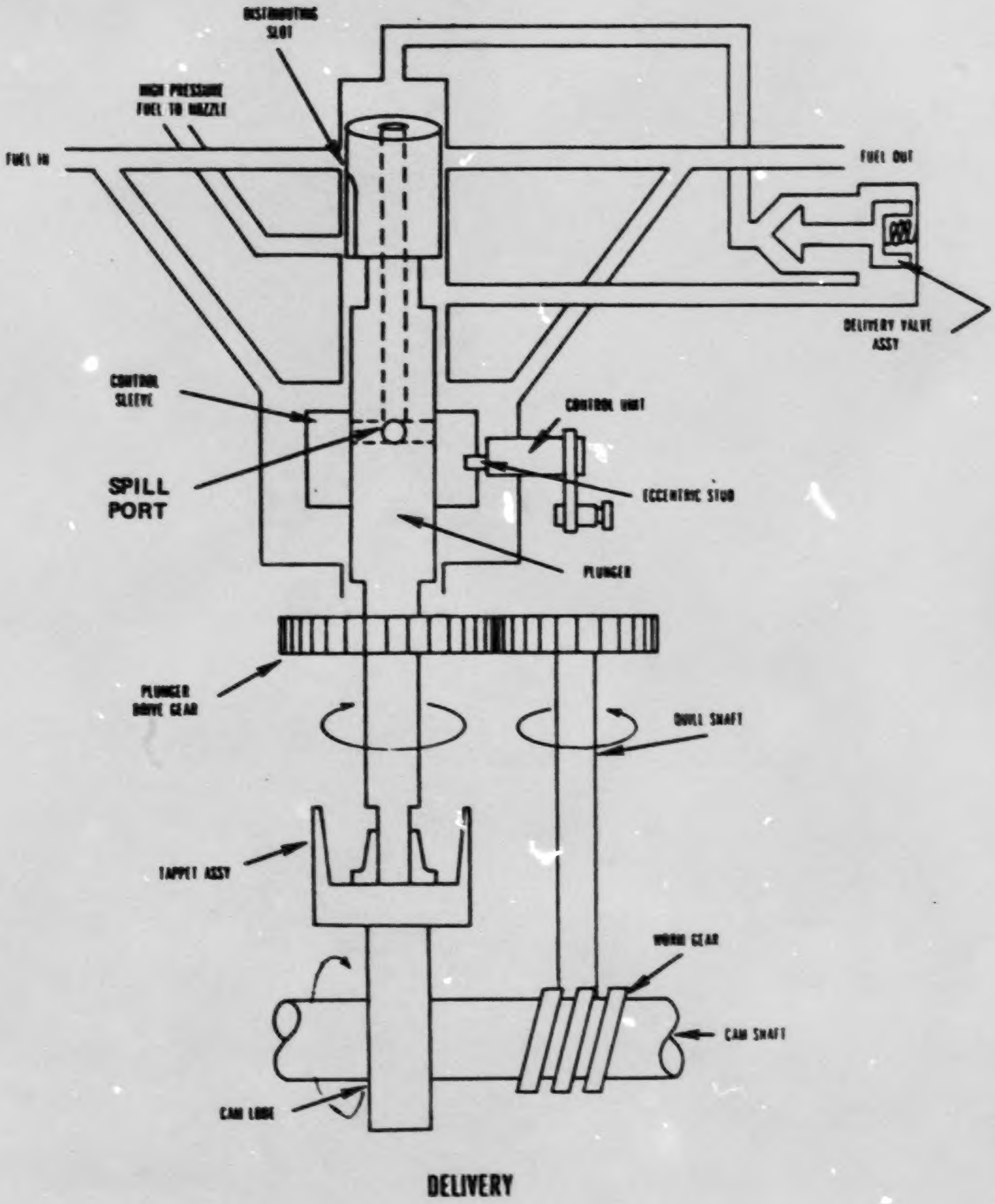
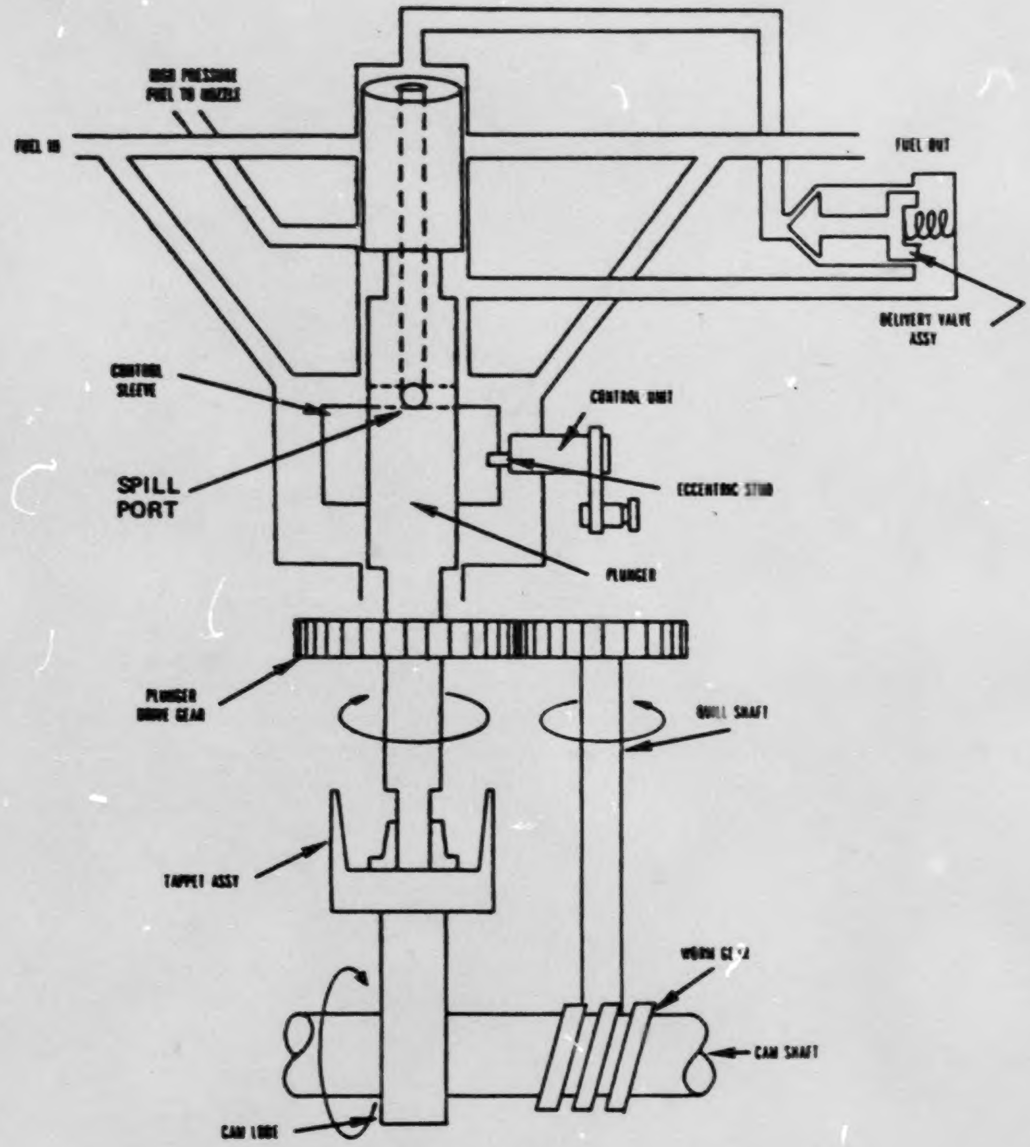

DISTRIBUTING SLOT
HIGH PRESSURE FUEL TO NOZZLE
FUEL IN
FUEL OUT
DELIVERY VALVE ASSY
CONTROL SLEEVE
CONTROL UNIT
SPILL PORT
ECCENTRIC STUD
PLUNGER
PLUNGER DRIVE GEAR
QUILL SHAFT
TAPPET ASSY
WORM GEAR
CAM SHAFT
CAM LOBE
DELIVERY

Figure 8-6. Pumping and metering—phase III.

PUMPING AND METERING—PHASE IV

PUMP, INJECTION, TYPE PSB 12BT

AVDS-1790-2 ENGINE


HIGH PRESSURE FUEL TO NOZZLE
FUEL IN
FUEL OUT
DELIVERY VALVE ASSY
CONTROL SLEEVE
CONTROL UNIT
SPILL PORT
ECCENTRIC STUD
PLUNGER
PLUNGER DRIVE GEAR
QUILL SHAFT
TAPPET ASSY
WORM GEAR
CAM SHAFT
CAM LOBE

END OF DELIVERY

Figure 8-7. Pumping and metering—phase IV.

(1) The fulcrum lever is pivoted not only at the sliding sleeve but also at its lower end to a yoke connected to the operating lever. The operating lever is intended to be actuated by a rod from the driver's seat or control panel. Through its connection with the fulcrum lever and its linkages to the pump control sleeve, the operating lever's position influences fuel delivery and engine speed.

(2) With the operating lever in a stationary position, the lower pivot of the fulcrum lever becomes fixed. If the engine load is increased the speed will momentarily decrease. The flyweights will lack the centrifugal force necessary to balance the spring forces on the sliding sleeve, which then shifts and moves the fulcrum lever and the control sleeve toward increased fuel delivery; the engine thereupon returns to its original speed. If it tends to exceed it, caused by a sudden diminishing of the load, the flyweights move farther out, their fingers shift the sliding sleeve against the opposing spring forces, the sliding sleeve moves the fulcrum lever and control sleeve to decreased fuel delivery, and the engine speed is reduced.

(3) The operating lever is connected to the fulcrum lever by a torsion spring bearing at one end against a tang on the operating lever and at the other end against a tang on the yoke at the bottom of the fulcrum lever. This torsion spring loads both tangs toward each other so that normally the operating lever and fulcrum lever act as though rigidly attached. However, when the engine speed differs, as a result of load changes, from that which is normal for the operating lever position, the tangs part momentarily until the governor picks up the change. This function serves to protect the governor and pump parts from unnecessarily high loads and stresses.

(4) The sliding sleeve is loaded against the forces of the flyweights by two governor springs. These springs are of such rate that the action of the flyweights at any given speed within the normal range is balanced by the spring forces after the sleeve has shifted. Therefore, at any given engine speed there is a corresponding definite sleeve position. As a result of this inherent governor stability, speed regulations of 3-1/2 to 5 percent and 7 to 13 percent are obtainable, depending upon the spring combination used and upon the position of the sleeve pivot pin in the fulcrum lever, which is adjustable.

(5) The fulcrum lever has a smoke limit cam attached to its upper end which limits the maximum fuel delivery, despite operating lever position, by contacting an adjustable stop plate, thus avoiding overloading the engine. In tractor applications, especially where low speed loads and increased torque are required, the torque control plate and smoke limit cam are adjusted to give a torque buildup at declining speeds. As engine load increases beyond the nominal stop setting, the speed decreases and the weights consequently move inward toward the shaft, moving the sleeve. This added load separates the tangs of the yoke and the operating lever and moves the yoke rearward and upward; the fulcrum lever, pivoted at the yoke, moves up with it. The fulcrum lever then pivots about the nose of the smoke cam against the stop plate. Since the control rod to the pump control sleeve is attached below this new pivot point, its action is opposite from usual and results in more fuel delivery and consequently more torque buildup.

(6) The face of the torque control plate inclines toward the pump at an angle so that as the cam nose rides up on it, the torque increases. The cam nose is adjustable and the higher it is set on the fulcrum lever, the further upward and inward it rides on the torque control plate, thus giving an adjustment of the torque buildup. Further adjustment can be made by changing the angle of the torque control plate, and a large increase can be had by using a profiled plate, with two surfaces in different planes, for this function.

e. **Pump data.**

(1) Type - PSB 12BT-110 GH-4900A1.

(2) Explanation of type designation.

(a) PS - single plunger.

(b) B - type; also indicates that there is a 6mm total plunger stroke and that the plunger diameter is in the 10 to 15mm range.

(c) T - refers to tandem placement of the hydraulic heads.

(d) 110 - the plunger is 110-tenths of a millimeter or 11mm.

(e) GH - refers to the type of governor used.

(f) 4900A - refers to customer specification data.

(g) 1 - refers to specification code number for speed range, governor springs, regulation, and fuel quantity.

8-5. TESTING PSB 12BT FUEL INJECTION PUMPS.

a. **Sequence of testing.** Testing the PSB 12BT pumps follows this general sequence:

(1) Fuel leakage test.

(2) Delivery valve test.

(3) Bleeder valve test.

(4) Injection pump timing.

(5) Adjusting fuel delivery of No 1 hydraulic head.

(6) Balancing fuel delivery from No 2 hydraulic head.

(7) Adjusting high speed and fuel shutoff.

Note. - The first two tests in the above sequence are performed with nozzle tester 4910-255-864. The remaining tests are performed on the fuel injection pump test stand 4910-817-7431.

b. **Fuel leakage test.** During rebuild of the PSB 12BT pump, all packings are replaced. To insure that there is no fuel leakage, the following test is performed.

(1) Remove the fuel housings and stems and the pump housing cover from injection pump. Plug the fuel outlet from No 1 hydraulic head, using 1/4-in pipe plug. Screw the connector stud, stamped N-31, into the hydraulic head inlet. Assemble flexible connector N-2 to the nozzle tester and the connector stud N-31, using connector nut N-4. Position the fuel plunger drive gear of No 1 hydraulic head so its slotted tooth alines with the punch-mark on the housing by rotating the camshaft, using camshaft turning wrench 10882894.

(2) Operate the nozzle tester, using slow steady strokes, until a pressure of 400 PSI is read on the gage. DO NOT allow fuel pressure to exceed 425 PSI.

(3) Pressure will now drop slowly. When pressure drops to 350 PSI, time the rate of drop to 250 PSI. If time of pressure drop is less than 30 seconds, an internal leak is present. Visually inspect for fuel leaks around fuel control unit, hydraulic head, and tappet. Fuel leakage at these points indicates a worn control unit or damaged packings which must be replaced.

c. **Delivery valve test.** To check delivery valve opening pressure:

(1) Position plunger so fuel will flow from one of the six outlets of the hydraulic head. Use camshaft turning wrench 10882894 to turn camshaft while slowly operating nozzle tester. When fuel flows from outlet, secure camshaft turning wrench so camshaft cannot rotate. Remove the plunger bore screw from the top of the hydraulic head and install plunger bore adapter N-41. Assemble plunger bore adapter to flexible connector N-2 with connector nut N-4. Make sure delivery valve spring seat is screwed tightly into delivery valve before making test.

(2) Operate nozzle tester, using slow steady strokes, while holding plastic spray collector cup under outlet port to collect fuel. Delivery valve should open between 250 and 400 PSI. This is determined by a sudden drop in the reading on the gage of the nozzle tester. If delivery valve fails to open within above pressures, the delivery valve spring must be replaced.

(3) Disconnect flexible connector from plunger bore adapter and remove adapters and pipe plug from No 1 hydraulic head and repeat leakage and delivery valve test on No 2 hydraulic.

d. **Mounting pump on the test stand.**

(1) Install the fuel housing and stems on the injection pump.

(2) Mount injection pump on bracket assembly (A, fig 8-8), using four hex nuts and plain washers on bracket mounting studs. Be sure rubber O-ring is seated in recess for sealing lube oil return port. Slide pump coupling hub (C, fig 8-8) on pump camshaft and secure with camshaft nut and lockwasher. Slide coupling sleeve (E, fig 8-9) on test stand drive hubs. Place pump and bracket on test stand mounting rails and slide toward drive hub. Mate sleeve to pump hub. Attach clamp bars and hand knobs (D, fig 8-9) to underside of pump mounting bracket and tighten securely.

(3) When using stand for first time, fill accumulators (A, fig 8-10) two-thirds full with test oil before installing nozzles to hasten delivery to graduates when testing.

(4) Screw nozzles and holders (F, fig 8-8) into accumulators, using nozzle adapter wrenches (G, fig 8-9). Do not overtighten as O-ring seal will be distorted, breaking seal between holder and accumulator. Do not install high pressure lines.

(5) Install fuel hose between discharge block marked "fuel pressure" and pump fuel inlet housing. Connect lube oil hose between lube pressure discharge block and pump fitting at left of governor cover. Lube oil return hose is connected between fitting on left side of pump mounting bracket and lube return discharge block. Connect remaining fuel hose to pump bleeder valve housing and place free end near drain hole in test stand drain pan.

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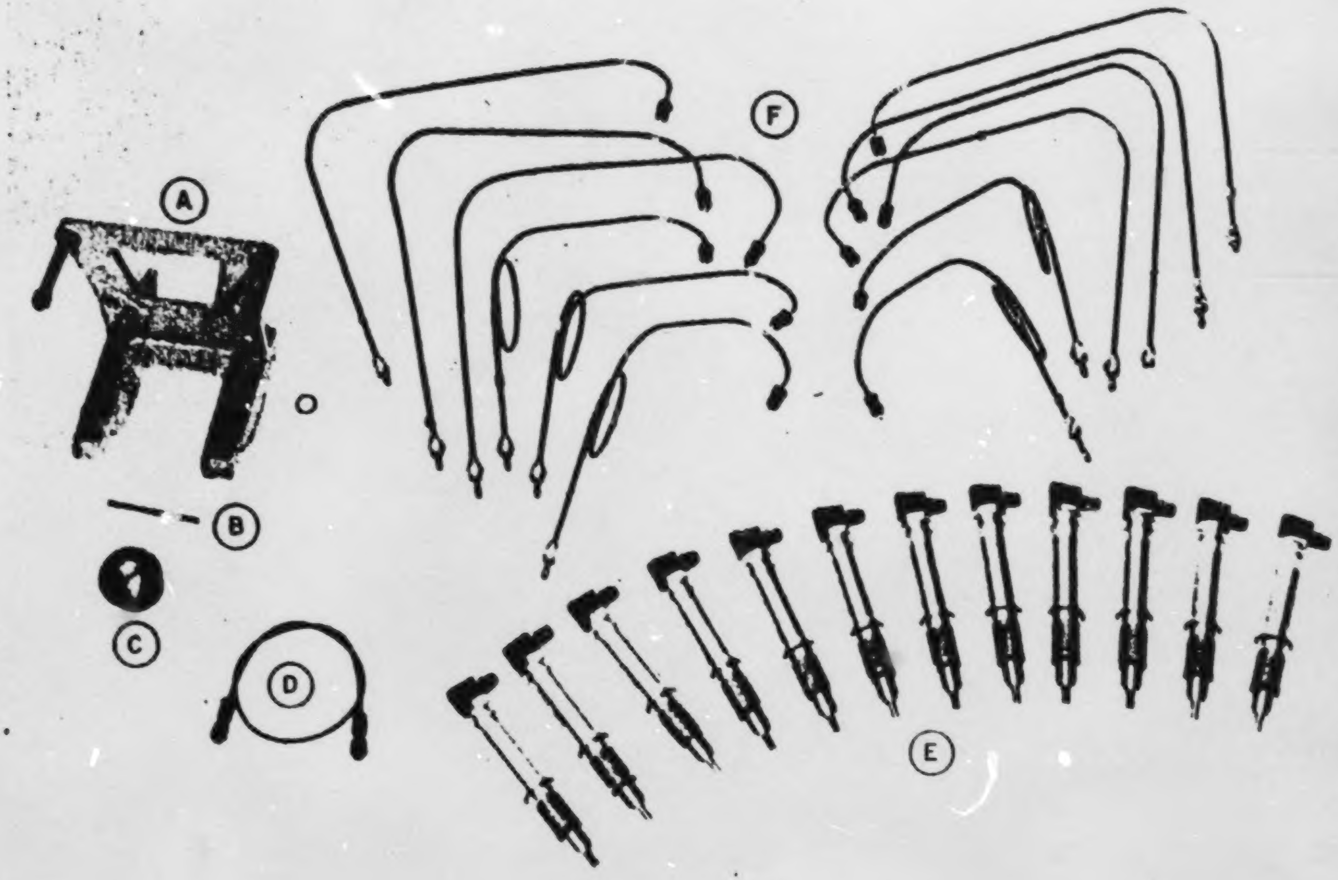

Figure 8-8. Test accessories for AM Bosch PSB 12BT injection pumps.

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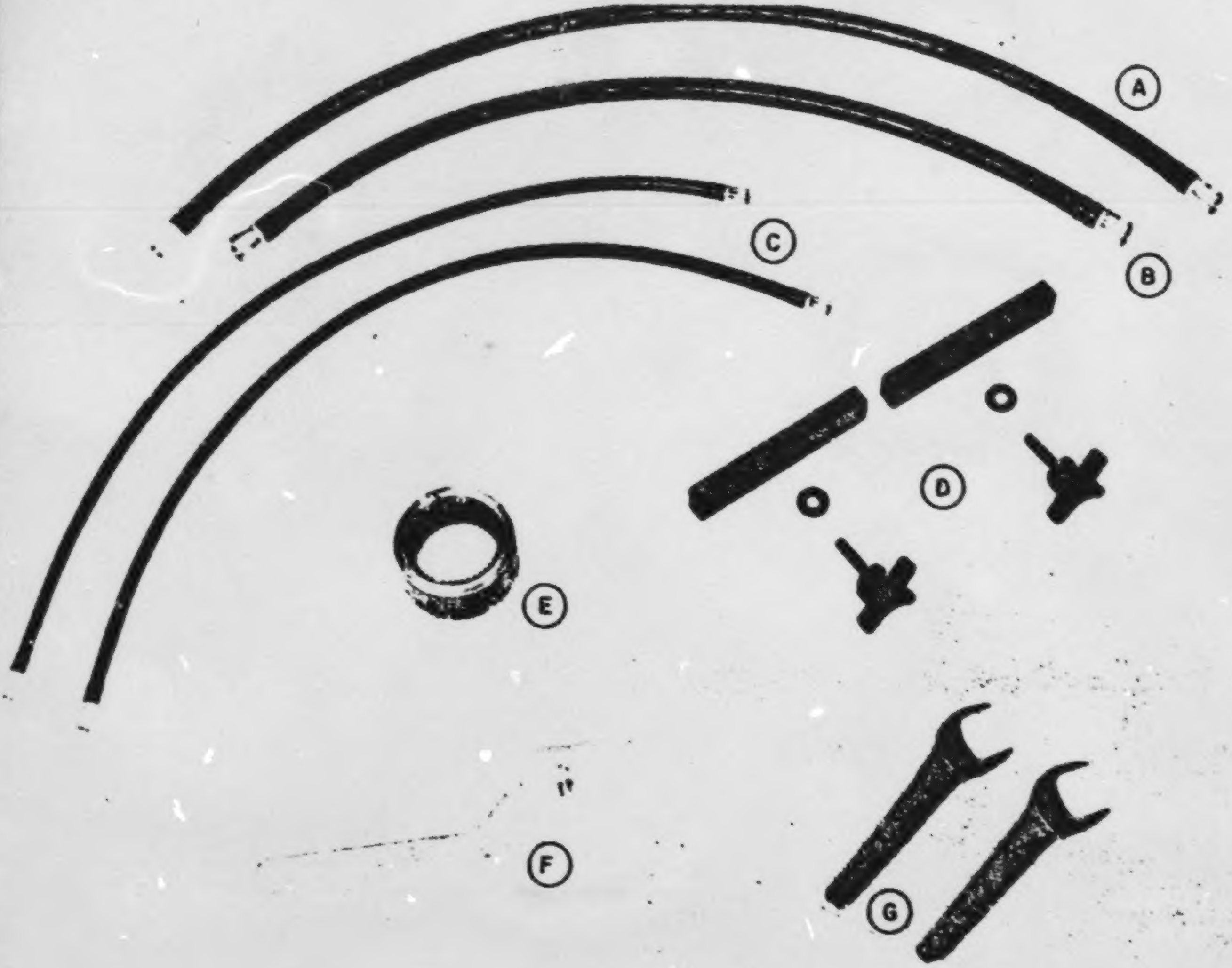
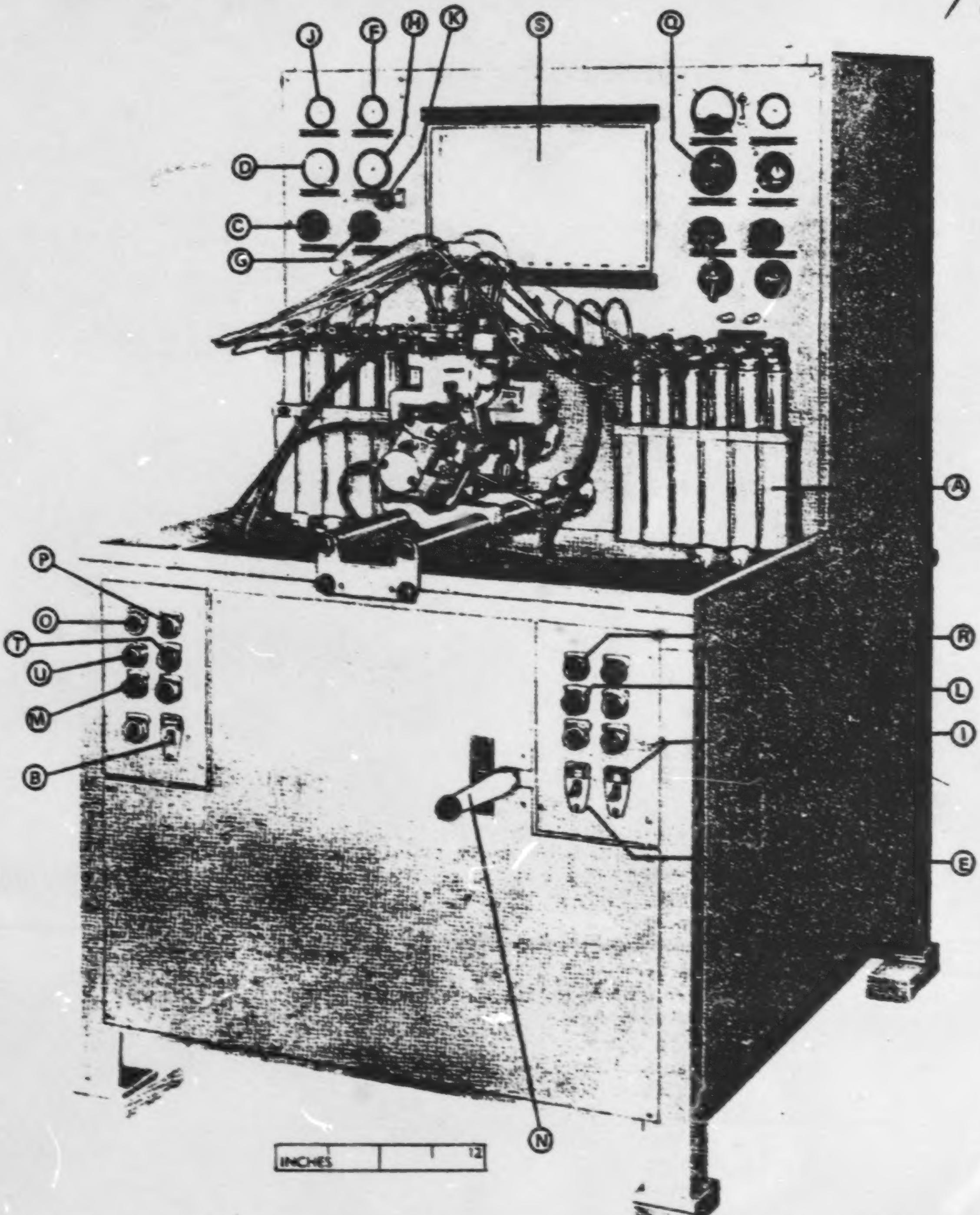


Figure 8-9. Basic tools and accessories for calibrating stand.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12

ORD K2997

Figure 8-10. PSB 12BT injection pump mounted on test stand.

(6) Place throttle spring (B, fig 8-8) between stud on pump mounting bracket and pump operating lever to hold lever in FULL THROTTLE position.

Note. - Key letters below refer to figure 8-10 unless otherwise indicated.

e. **Bleeder valve test.** Turn on auxiliary switch (B) to start test stand fuel pump. Turn fuel pressure regulator (C) clockwise until fuel begins to flow from the fuel return hose in drain pan. Observe reading on fuel pressure gage (D). If bleeder valve does not open at 35 to 38 PSI, adjust by adding or subtracting shims between bleeder valve and bleeder valve spring. When bleeder valve opens at correct pressure, turn off auxiliary switch (B) and connect free end of fuel hose to discharge block marked "FUEL RETURN" for following tests.

f. **Injection pump timing.**

(1) Connect high pressure lines (F, fig 8-9) to pump and nozzle holders. Lines are tagged 1L, 2L, 3R, etc, for ease in connection. Test nozzle and holder assemblies on left of test stand represent left-hand bank of engine and would read one through six from left to right. Connect these nozzles to No 1 hydraulic head.

(2) Back off the delivery valve spring seats in each hydraulic head.

(3) Turn on auxiliary switch (B) and adjust fuel pressure regulator (C) until fuel flows at 30 to 35 PSI. Bleed pump of all air by turning camshaft manually counterclockwise, using coupling sleeve spanner wrench (F, fig 8-9). After pump is bled, turn camshaft counterclockwise until slotted tooth of plunger drive gear appears in inspection window.

(4) Turn pressure regulator to reduce pressure to a minimum.

(5) Disconnect No 1R high pressure line from its nozzle and holder assembly. Slowly rotate camshaft clockwise until fuel just begins to flow out of No 1 fuel line. Set marker on test stand drive shaft to 0°. Continue rotating camshaft clockwise until fuel flow stops. This is the port closing position.

(6) At port closing, the PC mark on the pump housing should aline with the slotted tooth on the plunger drive gear. At the same time, the short tooth must be visible in the timing plughole at the front of the pump. Turn off auxiliary switch (B) and connect 1R high pressure line to test nozzle.

(7) Repeat above procedure with No 2L fuel outlet to determine the port closing of No 1 hydraulic head. Port closing for No 2L fuel outlet should occur 30° after No 1R fuel outlet. At conclusion of tests tighten delivery valve spring seats.

(8) It is not necessary to mark the port closing of No 1 hydraulic head. The check of No 1R fuel outlet is to determine whether or not the internal parts of the injection pump have been properly installed and adjusted during pump assembly.

g. **Adjusting fuel delivery of No 1 hydraulic head.** Ready the test stand by performing the following steps (fig 8-10).

(1) Turn on auxiliary switch (B).

(2) Turn on lube oil heat switch (E) to bring oil temperature to 150° F on lube oil temperature gage (F).

(3) Adjust lube oil regulator (G) to obtain 25 to 30 PSI on lube oil pressure gage (H).

(4) Turn on fuel heat switch (I) to bring fuel temperature to 115° to 120° F on the fuel temperature gage (J).

(5) Adjust fuel regulator (C) to obtain 30 to 35 PSI on the fuel pressure gage (D).

(6) Position fuel dumping lever (K) up.

(7) Set count selector switch (L) to 1,000. Two revolutions of camshaft are necessary for a single injection from the pump. Thus, when counter is set for 1,000 it will be equivalent to 500 injection pump strokes.

(8) Set forward-reverse switch (M) to FORWARD for clockwise rotation of drive coupling.

(9) Turn shifting crank (N) to high range.

(10) Set pump operating lever in FULL SPEED position.

(11) Push test stand start button (O) and increase speed to 600 RPM by pushing fast button (P). Maintain 600 RPM speed for a 5-minute warmup period.

(12) After pump warmup, push fast button (P) and increase test stand speed to 2,440 RPM as indicated on tachometer (Q). Push count button (R) and hold momentarily. Record delivery for No 1 hydraulic head at end of count. Work on the basis of average delivery. Record the delivery of the burettes (S) for No 1 hydraulic head, add them together, and divide by six for average delivery.

(13) It is good practice to use a total of three runs for determining average delivery. Use pumping lever (K) to empty burettes (S) after each run.

(14) Average delivery for No 1 hydraulic head should be 104 to 106 cc. If the delivery is above or below this average, remove governor cover and move the torque control stop plate by means of the adjusting nut. Continue collecting fuel and adjusting torque control stop plate until average delivery falls within 104 to 106 cc.

h. **Balancing delivery from No 2 hydraulic head.** Operate pump at 2,440 RPM as outlined above and record average fuel delivery for No 2 hydraulic head. If delivery is above or below average delivery for No 1 hydraulic head, adjust the elastic stop nut on the fuel control yoke assembly.

i. **Droop screw adjustment.** Operate pump at 1,000 RPM and adjust droop screw to obtain 75 to 77 cc.

j. **Adjusting high speed and fuel shutoff.**

(1) Operate test stand at 2,570 RPM. Adjust high speed adjusting screw (vertical screw to left of operating lever) to obtain 40 to 55 cc.

(2) Increase test stand speed to check for fuel shutoff. Fuel delivery should cease at approximately 2,670 RPM. If not, the high speed adjusting screw and/or governor inner spring must be adjusted.

(3) Reduce test stand speed to minimum by pushing slow button (T). When speed reaches minimum, push stop button (U) and turn shifting crank (N) to the low range. Start test stand and adjust speed to 150 RPM. Set count button (R) and collect fuel in burettes (S). Fuel delivery must be at least 40 cc in each burette.

k. Idle adjustment. Operate pump at 650 RPM. Set idle adjusting screw to obtain 25 to 27 cc. If this is not possible, the outer governor spring tension must be adjusted.

l. Solenoid shutoff test. Operate pump at 2, 440 RPM and start count. Push 24-V button to energize solenoid. Fuel delivery should cut off cleanly.

m. Test stand shutdown and pump removel.

(1) Reduce test stand speed to minimum by pushing slow button (T). Push test stand stop button (U).

(2) Turn off lube oil (E) and fuel heat (I) switches.

(3) Turn off auxiliary switch (B).

(4) When pump is cool enough to handle, disconnect all lines and remove pump from test stand.

(5) Install governor and pump housing covers.

SECTION IX. FUEL INJECTION PUMP (AMERICAN BOSCH MODEL PSB 6A) PRELIMINARY TESTING AND ADJUSTING

Note. - For exact specifications and pump models, refer to TM 9-2910-226-35. For identification, see figure 9-1.

9-1. FUEL LEAKAGE. All O-rings must be replaced at overhaul. To insure that there is no leakage at the hydraulic heads, filter screw, and control unit, the following test must be performed.

a. Remove the supply pump, bleeder valve, timing window cover, and fuel supply fitting.

b. Install pump with advance unit onto stand.

Note. - Do not attach any lines or fittings.

c. Plug fuel outlet from pump hydraulic head (use 1/4-in pipe plug).

d. Connect nozzle tester FSN 491-255-8641, using the proper adapters, and flex line to the fuel supply orifice at the pump hydraulic head.

e. Turn the pump shaft until scribed-painted tooth is alined with the housing reference mark in the timing window.

f. Slowly actuate the tester until a pressure reading of 400 PSI is attained.

Note. - Do not allow the pressure to exceed 425 PSI.

g. The pressure will now drop slowly. When it drops to 350 PSI, time the rate of drop to 250 PSI. If the time of pressure drop is less than 30 seconds, an internal leak is present.

h. Visual inspection.

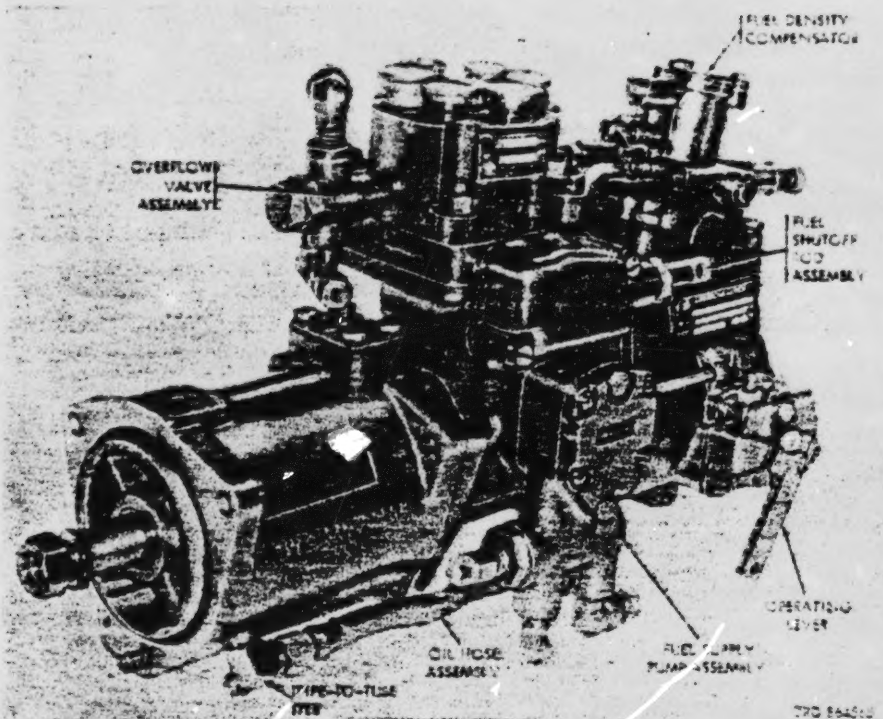
(1) Check the lube oil inlet T-fitting on the advance unit. Leakage at this point indicates that the filter screw O-ring gasket is damaged.

(2) Presence of oil at the control unit indicates a worn control unit shaft or a damaged O-ring.

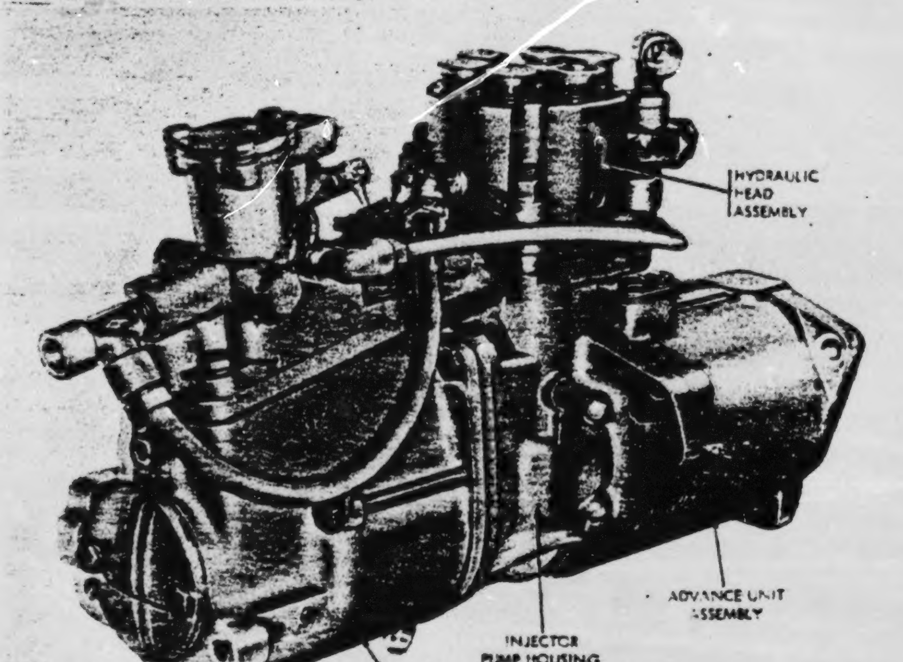
(3) Excessive leakage past the tappet assembly only, as observed through the supply pump opening, indicates that the head assembly O-ring gasket is damaged or the pump has an excessively worn plunger.

(4) An external leak at the bottom of the head assembly flange, where it seats on the housing, indicates that the rubber O-ring gasket is damaged.

(5) Remove all of the test fittings and fixtures except the 1/4-in pipe plug in the fuel outlet side of the hydraulic head; i.e., after test is valid.


FUEL DENSITY COMPENSATOR
OVERFLOW VALVE ASSEMBLY
FUEL SHUTOFF ROD ASSEMBLY
OPERATING LEVER
FUEL SUPPLY PUMP ASSEMBLY
OIL HOSE ASSEMBLY
PIPE-TO-TUBE TEE
ORD E64565

Left front view.


HYDRAULIC HEAD ASSEMBLY
ADVANCE UNIT ASSEMBLY
INJECTOR PUMP HOUSING
GOVERNOR
ORD E64566

Right rear view.

Figure 9-1. Metering and distributing fuel injector pump assembly.

9-2. TIMING.

a. Adjust fuel and lube pressure to a minimum (ccw).

b. Connect the fuel pressure line from the stand to the inlet side of the hydraulic head.

c. Connect the lube pressure and drain lines to pump and stand.

d. Turn the auxiliary motor switch on.

e. Adjust the fuel and lube pressures to 10 PSI.

f. Loosen 1/4-in pipe plug and turn pump shaft manually (bleeding of head is essential). Tighten plug.

g. Turn the auxiliary motor switch off.

h. Remove delivery valve cap, valve, and spring. Replace cap securely.

Note. - Use caution so surfaces are not scratched.

i. Remove cover from advance unit timing window.

j. Secure operating lever (pump) in FULL LOAD position.

Note. - Use operating lever retaining spring.

k. Rotate pump shaft clockwise (normal rotation) until scribed-painted tooth of the plunger drive gear appears in the inspection window.

l. Turn the auxiliary motor switch on.

m. Turn pump drive shaft until fuel stops flowing out of No 1 outlet; this is port closing. At this point, the scribe mark on the coupling rim must register with the pointer. The scribed-painted tooth in the timing window will be about one tooth off the housing reference mark.

n. Turn auxiliary motor switch off.

o. This check will also prove whether internal parts of the pump have been properly phased.

p. Replace timing window cover on advance unit.

Note. - Do not disconnect or remove other adapters - continue.

9-3. DELIVERY VALVE. To check the opening pressure of the delivery valve, the plunger must be positioned so the fuel will pass its metering slot and be allowed to flow out one of the head outlets.

a. Turn the auxiliary switch on.

b. Slowly rotate the pump camshaft until fuel flows out the No 1 fuel outlet in the head. Lock camshaft with holding tool.

Note. - Pump is on port closing for No 1 outlet.

c. Turn auxiliary switch off.

d. Carefully replace the delivery valve and spring. Secure cap and tighten to specification.

e. Remove the plunger bore screw and screw the delivery valve test adapter into the plunger bore.

f. Place a 1/4-in pipe plug in the fuel inlet of the hydraulic head.

g. Connect the nozzle tester FSN 4910-255-8641 to the delivery valve test adapter hose and fitting.

h. Slowly build up the fuel pressure with the nozzle tester while holding a suitable container or rag over the No 1 outlet port to catch the fuel. The delivery valve should open between 250 to 400 PSI. This is determined by a sudden drop in the reading on the gage of the nozzle tester.

i. Remove the 1/4-in pipe plugs from the hydraulic head and disconnect the nozzle tester. Remove the delivery valve test adapter. Replace the plunger bore screw.

9-4. BLEEDER VALVE.

a. Replace the bleeder valve assembly to the pump hydraulic head.

b. Connect fuel inlet line to the pump hydraulic head.

c. Place caps over nozzle leakoff fittings on the bleeder valve.

d. Connect the fuel drain line to the bleeder valve.

e. Turn the auxiliary motor switch on.

f. Adjust the fuel pressure regulator knob until fuel flows from the bleeder valve drain line. Adjust the bleeder valve to open at 27 to 33 PSI by adding or subtracting shims to the valve. Refer to TM 9-2910-226-35 for specific model application.

g. Turn the auxiliary motor switch off.

Note. - The bleeder valve must maintain a pressure of approximately 15 PSI at engine idle (550 RPM).

h. Connect the fuel drain line to the stand.

9-5. FUEL DELIVERY.

Note. - A fuel compensator known to be calibrated must be mounted on the pump.

a. Install test nozzles and high pressure lines.

b. Turn the auxiliary motor switch on.

c. Turn oil heater switch on to bring oil temperature to 150° on the oil temperature gage.

d. Turn the oil pressure regulator until an oil pressure of 35 to 45 PSI is obtained on the oil pressure gage.

e. Turn the fuel heater switch on to bring fuel temperature between 115° and 120° on the fuel temperature gage.

f. Turn the fuel pressure regulator knob until fuel flows at 27 to 35 PSI as indicated on the fuel pressure gage (regulated by bleeder valve).

g. Set test stand drive counter switch at 1,000.

h. Set test stand drive rotation switch at the REVERSE position.

i. Set test stand drive shifting lever in high.

j. Push stand start button and adjust speed to 600 RPM. Maintain this speed for 5 minutes (warmup time).

k. Adjust to 2,600 RPM and record the average delivery. Adjust the fuel delivery to obtain an average reading of 36 to 38 cc on 500 injection strokes (1,000 RPM). If the delivery is above or below this average, adjust the guide screw (on compensator). Moving the screw into the housing moves the stop plate toward the smoke limit cam and decreases fuel delivery. Insure locknuts are tight.

l. Reduce speed to 1,400 RPM and check for average delivery of 39.5 to 41.5 cc. Again adjust guide screw to obtain proper reading.

m. Increase speed to 2,850 RPM. Fuel delivery should stop. Adjust high speed screw for correct reading.

Note. - The high speed adjustment affects fuel delivery at lower RPM; therefore, a combination of adjustments may be necessary to obtain the desired fuel delivery readings. If fuel flow cannot be adjusted to limits, check the smoke limit cam angle and set to 60°.

n. Stop test stand and turn shifting crank to low range. Adjust speed to 150 RPM and check for fuel delivery of at least 30 cc. A lower reading would indicate a worn plunger.

o. Operate pump at 550 RPM and check for fuel delivery of 13 to 14 cc. Adjust idle screw to obtain correct reading.

p. After this last adjustment the pump is properly calibrated and ready to be removed from the test stand.

SECTION X. FUEL DENSITY COMPENSATOR (PSB 6A PUMP)

10-1. GENERAL DESCRIPTION. The multifuel engine (465-series) operates on fuels which have a significant variation in density and heat value per gallon. The characteristics of the fuels used in the engine show a definite relationship between fuel viscosity and heating value. The fuel density compensator (fig 10-1) takes this into account by making the viscosity characteristic a sensed variable. In the compensator the fuel is passed in series through two orifices of widely different flow characteristics (sizes). A change in viscosity of the fuel flowing through these orifices causes a pressure drop, which moves a servopiston to vary the full load stop plate.

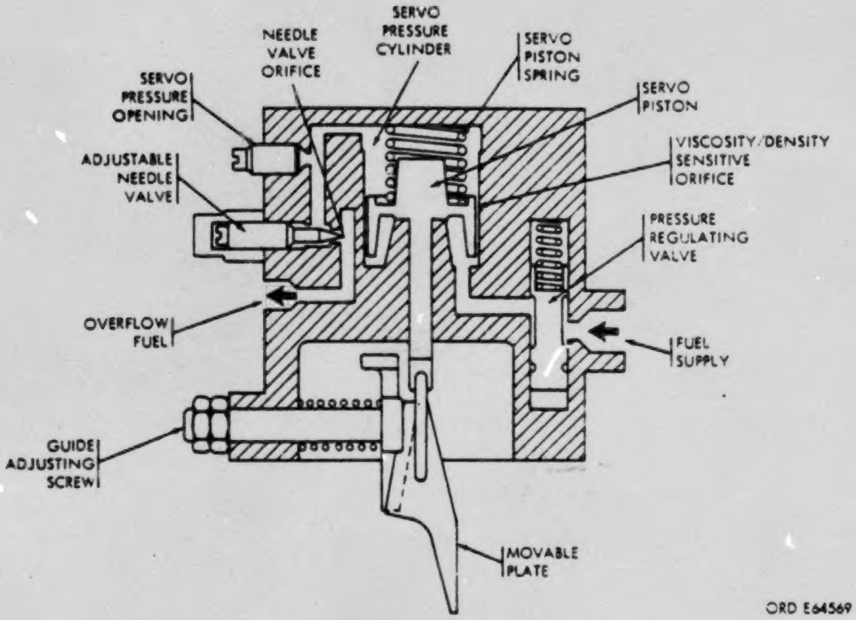

SERVO PRESSURE CYLINDER
NEEDLE VALVE ORIFICE
SERVO PISTON SPRING
SERVO PRESSURE OPENING
SERVO PISTON
VISCOSITY/DENSITY SENSITIVE ORIFICE
ADJUSTABLE NEEDLE VALVE
PRESSURE REGULATING VALVE
OVERFLOW FUEL
FUEL SUPPLY
GUIDE ADJUSTING SCREW
MOVABLE PLATE
ORD E64569

Figure 10-1. Fuel density compensator - schematic view.

10-2. OPERATION. The fuel supply is admitted to a pressure regulating valve where the supply pressure is reduced to a constant regulated pressure of 20 PSI. The fuel flows through the first orifice formed by a close fitting piston in a cylinder. From the servopressure cylinder the fuel flows to the second orifice, which is a sharp edge, adjustable needle valve. The two orifices working at widely different restrictions to the flow of fuel form a system sensitive to viscosity changes. The pressure difference between the two orifices will change the servopressure in direct relationship to the viscosity of the fuel flowing. The position of the spring-loaded piston is varied in accordance with these servopressure changes. The piston is connected by a link to the wedge-shaped, movable (vertical) stop plate. The stop plate, in turn, serves as a limiting point for the smoke limit cam and fulcrum lever travel to the maximum fuel position. Upward movement of the stop plate, due to compensator sensing, will increase fuel delivery.

Note. - Only qualified fuel and electric repairmen are authorized to test and calibrate the fuel density compensator.

SECTION XI. INJECTION PUMP APE 6BB (AMERICAN BOSCH)

11-1. GENERAL. The fuel injection system of the Mack model ENDT 673 engine consists of the injection pump complete with governor, injector nozzles and holders, delivery and overflow fuel lines, and filters. The injection pump drives a fuel supply pump that draws fuel oil through the primary filter and pumps it through the secondary filter to the injection pump. The supply pump is equipped with a handpump for priming the fuel system. The injection pump meters and delivers at high pressure and correct timing all the fuel required for engine operation. The governor controls the fuel volume in direct ratio to the position of the accelerator pedal. It also prevents overspeeding of the engine when operation is on downhill condition.

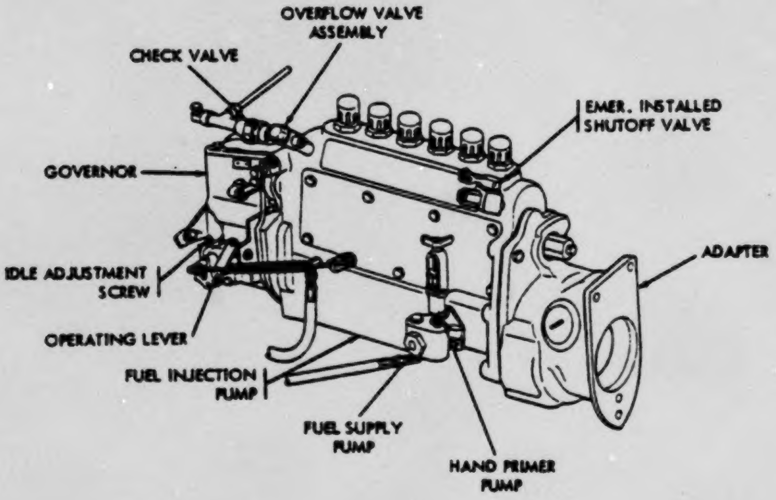


Figure 11-1. Fuel injection pump assembly.

11-2. OPERATING PRINCIPLES.

a. **General operation.** In the Mack model ENDT 673 engine, each cylinder has an individual injection pump which meters the fuel and delivers it under high pressure to the combustion chamber. The individual pumps are mounted in a common housing, are operated by a common camshaft, and utilize the same control mechanism to insure an equal amount of fuel in each cylinder at the proper time. Fuel oil is drawn through the primary filter by the supply pump. The supply pump forces the fuel through the secondary filter to the injection pumps. The supply pump must maintain a minimum pressure of 12-PSI flow from the secondary filter. The fuel injection pumps force a measured amount of fuel through high-pressure lines to the spray nozzles in the combustion chambers. Excess fuel flows from the injection pumps through both an overflow valve rated at 15 PSI and a check valve on the common housing and is returned to the fuel supply tank. Excess fuel in the injection nozzle also returns to the fuel tank.

b. Fuel injection pump.

(1) The pump is mounted on the engine in such a manner as to permit it to be driven by the engine timing gears. The cam lobes on the pump camshaft cause upward movement of the plungers, and springs produce the downward movement. The cams are arranged to actuate the individual injection pumps in the same sequence as the firing order of the engine (1-5-3-6-2-4). The injection pump camshaft is driven at one-half the engine speed on the Mack 4-cycle engine.

(2) The individual pumps are the lapped plunger, constant-stroke metering bypass type. The quantity of fuel delivered to the spray nozzle is regulated by the time that the plunger covers the bypass port. The plunger stroke length remains constant at all loads and speeds. The injection must be timed to occur 29° BTC as demanded by the requirement of the engine. Volumetric control is effected by rotating the plunger. Two ports lead to the plunger barrel as shown in figure 11-2; one is the inlet and the other is the bypass port. The plunger has a groove around its circumference which has a circular lower edge and a helical upper edge. This space is connected to the plunger top by a vertical bypass slot allowing any fuel above the plunger to flow into the helical space. Two lugs at the lower end of the plunger engage a control sleeve around the plunger barrel. The upper portion of this sleeve is fastened to a gear segment which meshes with a horizontal tooth control rack. Any movement of the control rack rotates the outer sleeve and plunger, through its lugs, relative to the bypass port in the stationary pump barrel. Movement of the control rack rotates each injection pump an equal amount to provide an equal delivery of fuel to each cylinder.

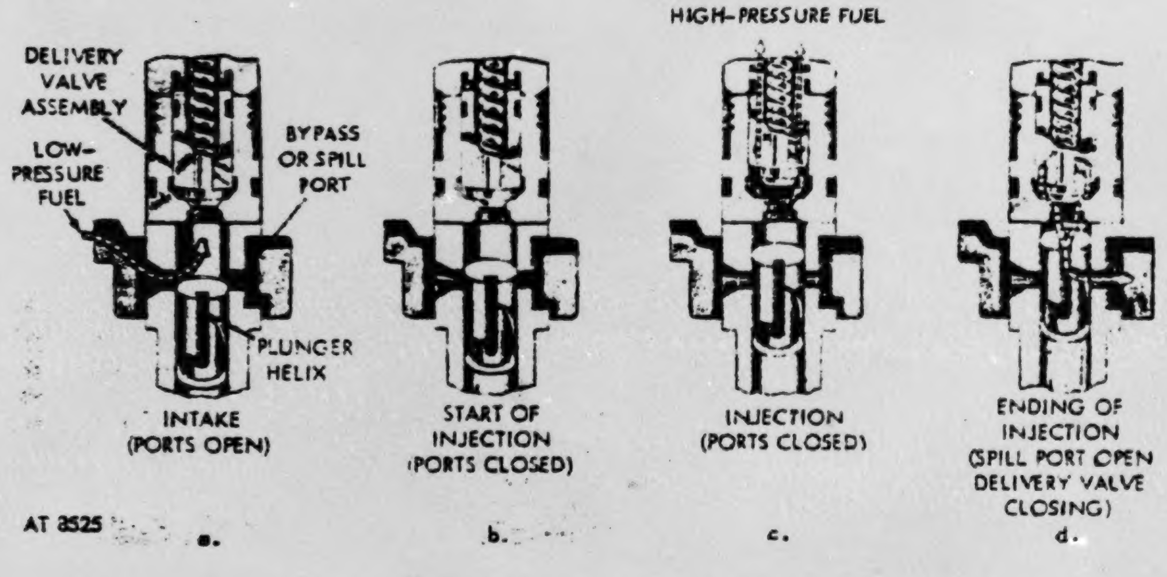

HIGH-PRESSURE FUEL
DELIVERY VALVE ASSEMBLY
LOW-PRESSURE FUEL
BYPASS OR SPILL PORT
PLUNGER HELIX
INTAKE (PORTS OPEN)
START OF INJECTION (PORTS CLOSED)
INJECTION (PORTS CLOSED)
ENDING OF INJECTION (SPILL PORT OPEN DELIVERY VALVE CLOSING)
AT 8525
a.
b.
c.
d.

Figure 11-2. Fuel injector pumping principle.

(3) Fuel from the pump fuel sump, under pressure from the supply pump, rushes into the barrel as soon as the upper edge of the plunger uncovers the two opposite ports in the barrel. This action begins during the downward stroke of the plunger, and the ports remain open as the plunger starts moving upward. When the plunger covers the ports on its upward stroke, cutting off the fuel supply, the pressure exerted on the fuel causes the spring-loaded delivery valve to unseat, permitting the fuel to discharge into the high-pressure tubing which leads to the spray nozzle. The high-pressure delivery of fuel ceases as soon as the helix on the plunger uncovers the bypass port in the barrel. At this instant, the fuel under pressure above the plunger is returned to the sump by way of the vertical groove and the helix uncovering the bypass port, thereby relieving the pressure on the delivery valve. The delivery valve is quickly returned to its seat by the combined action of its spring and the great difference in pressure that exists between the barrel and the high-pressure line. In returning to its seat, the delivery valve performs a double function: it prevents excessive draining of the fuel from the high-pressure line, and it relieves the pressure in the high-pressure line. This pressure relief is accomplished by the retreat of an accurately lapped displacement piston in the delivery valve. Before the delivery valve actually resets, it reduces the pressure in the high pressure line by increasing the volume therein by a quantity equal to the volume of the displacement piston.

(4) The positions of the plunger from no fuel to maximum fuel delivery are shown in figures 11-3, 11-4, and 11-5. For maximum delivery, the plunger is rotated in the barrel so that it will nearly complete its full stroke before the helix indexes with the bypass port. For zero delivery, the plunger is rotated in its barrel until the vertical groove alines with the bypass port. In this position, the pressure chamber is connected, through the groove, with the sump during the full plunger stroke. Any fuel delivery volume between zero and maximum can be obtained by moving the control rack in or out. The movement of the control rack causes the plungers to rotate a proportionate amount. The rack controls the position of all six plungers simultaneously, thereby insuring the injection of equal amounts of fuel in each cylinder of the engine.

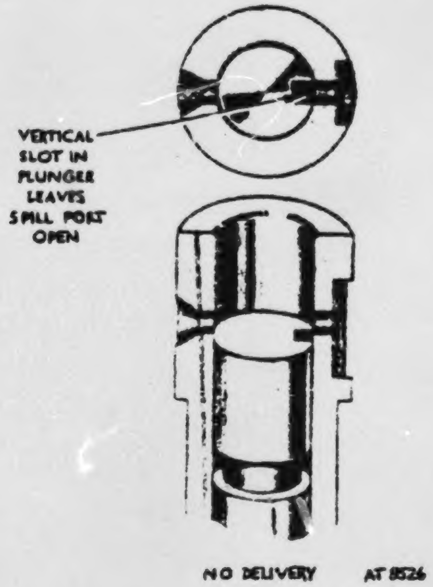


Figure 11-3. Fuel injector plunger no-fuel delivery position.

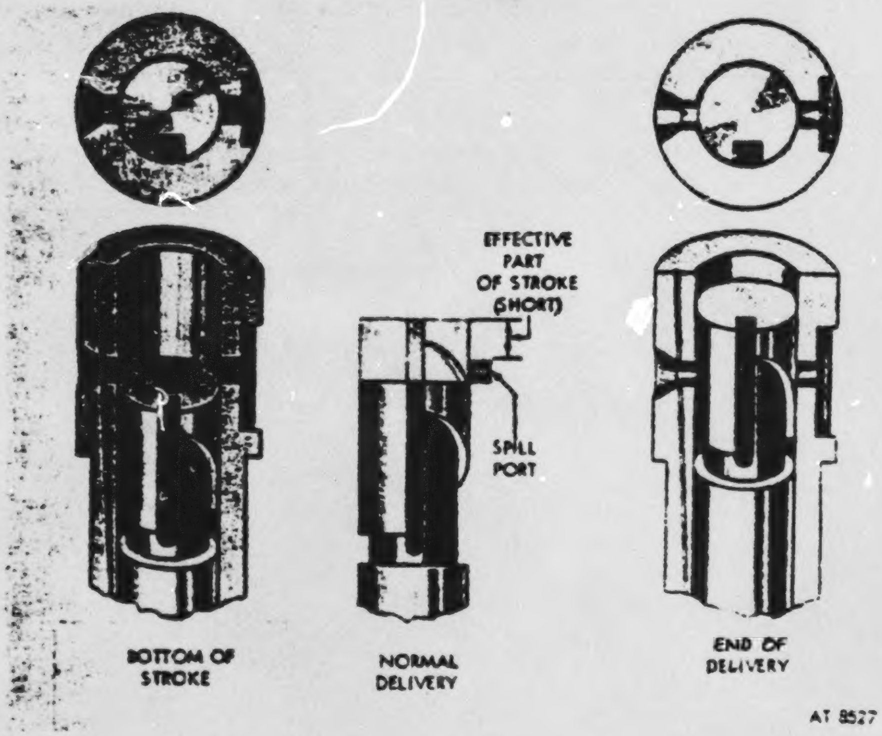

EFFECTIVE PART OF STROKE (SHORT)
SPILL PORT
BOTTOM OF STROKE
NORMAL DELIVERY
END OF DELIVERY
AT 8527

Figure 11-4. Fuel injector plunger—normal fuel delivery position.

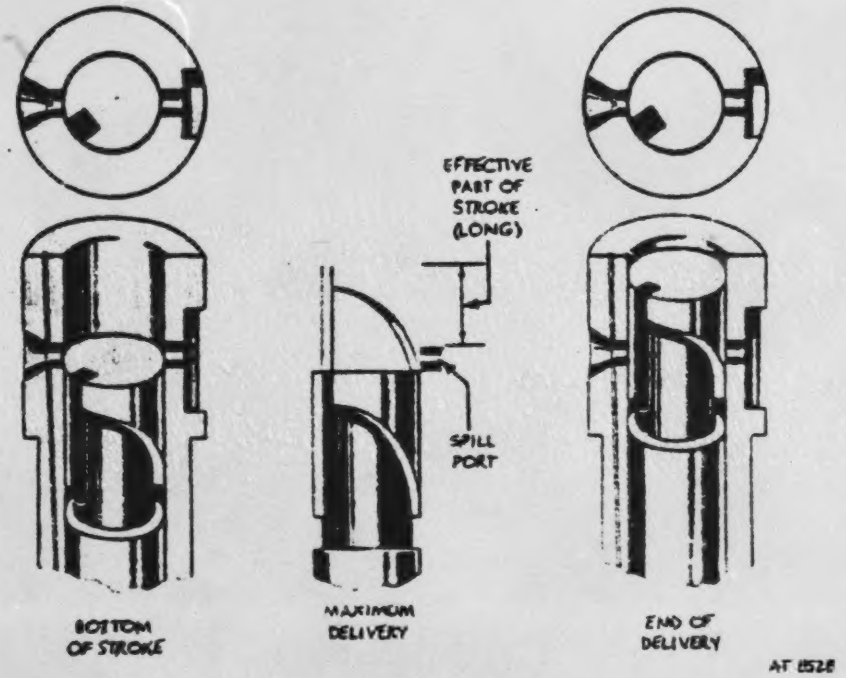

EFFECTIVE PART OF STROKE (LONG)
SPILL PORT
BOTTOM OF STROKE
MAXIMUM DELIVERY
END OF DELIVERY
AT 8528

Figure 11-5. Fuel injector plunger—maximum fuel delivery position.

(5) The pump is supplied with engine lubricating oil from the engine lubrication system on an intermittent basis, to lubricate the cams, roller bearings, tappet assemblies, and governor. The intermittent feed of lubricating oil to the injection pump is controlled by the movement of the No 6 tappet assembly. Figure 11-6 illustrates the tappet assembly at its highest position, allowing a small quantity of oil to flow into the pump camshaft section with each rotation of the camshaft. Figure 11-6 also illustrates the tappet assembly at its lowest position, where the lubricating oil inlet is blocked and oil is prevented from entering the pump. A lubricating oil drain hole at the drive end of the pump permits excess oil to drain back to the engine crankcase while retaining the required amount in the pump and governor. With this arrangement, it is necessary neither to add to nor change the lubricating oil in the injection pump, and no provision for checking the level is required.

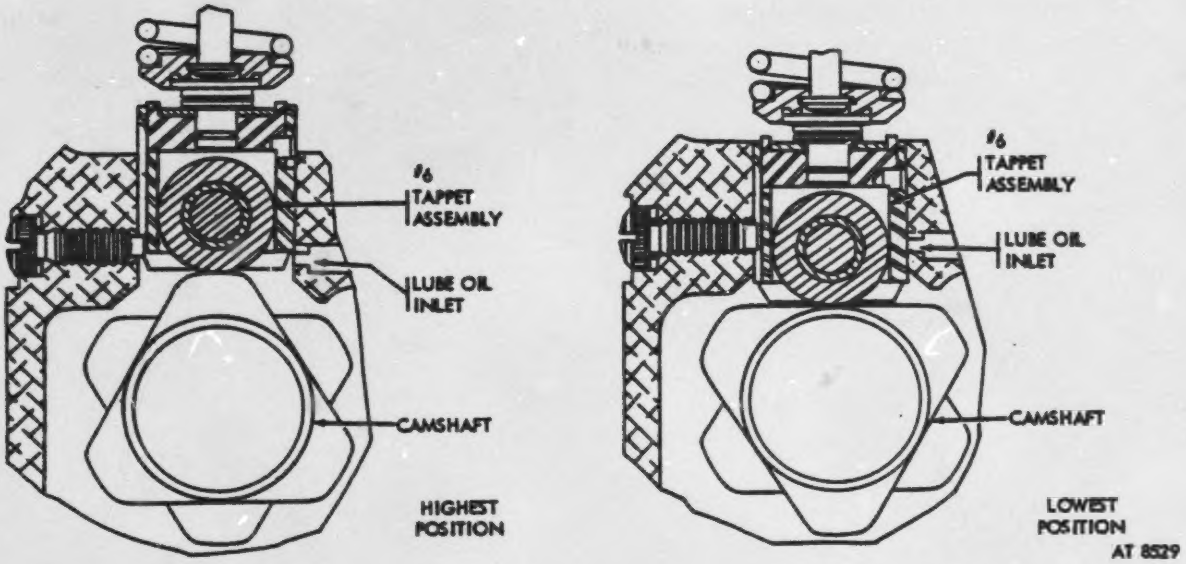


Figure 11-6. Fuel injector lubrication—tappet raised and oil inlet opened—tappet down and oil inlet cut off.

c. Injector nozzle and nozzle holder.

(1) General. For proper engine performance, the fuel oil must be injected into the combustion chamber in a definite spray pattern. This is accomplished by the injector spray nozzle which is held in the correct position in the cylinder head by the nozzle holder. The four-orifice nozzle and holder used in the Mack model ENDT 673 engine is shown in figure 11-7.

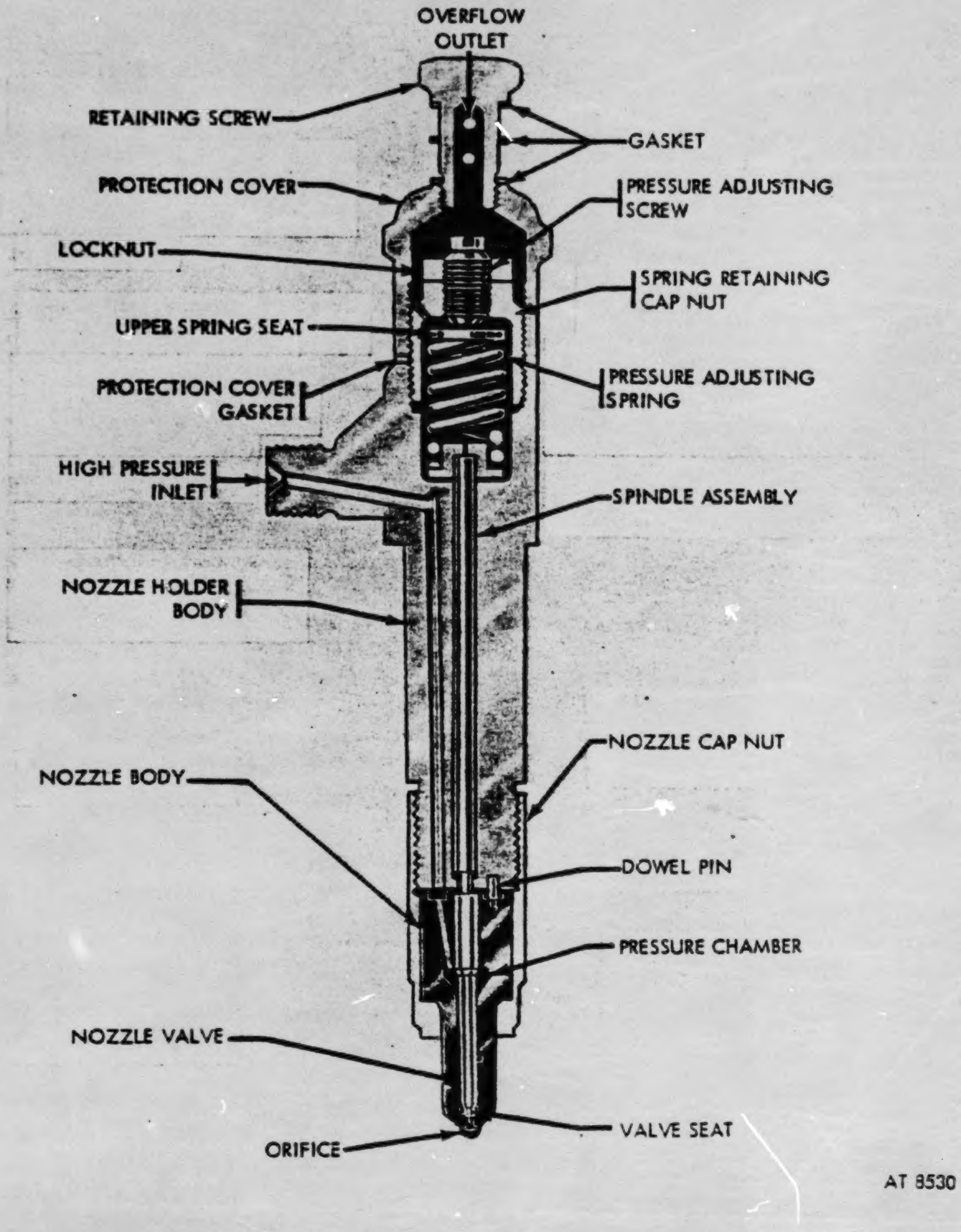

OVERFLOW OUTLET
RETAINING SCREW
GASKET
PROTECTION COVER
PRESSURE ADJUSTING SCREW
LOCKNUT
SPRING RETAINING CAP NUT
UPPER SPRING SEAT
PROTECTION COVER GASKET
PRESSURE ADJUSTING SPRING
HIGH PRESSURE INLET
SPINDLE ASSEMBLY
NOZZLE HOLDER BODY
NOZZLE CAP NUT
NOZZLE BODY
DOWEL PIN
PRESSURE CHAMBER
NOZZLE VALVE
VALVE SEAT
ORIFICE
AT 8530

Figure 11-7. Fuel injector nozzle and holder assembly.

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(2) Operation. The fuel, delivered at the proper time by the injection pump, flows through the high-pressure line and enters the nozzle holder inlet. It then flows through a duct in the holder and nozzle body into the pressure chamber of the spray nozzle above the valve seat. At the moment the fuel pressure, developed by the injection pump, exceeds the pressure exerted by the pressure-adjusting spring, the nozzle valve is lifted off its seat and the fuel is forced through the orifices and sprayed into the combustion chamber of the engine. As the helix of the injection pump plunger reaches the bypass port, the pump ceases to deliver fuel and the pressure spring returns the nozzle valve to its seat. A controlled amount of seepage of fuel between the close-tolerance, lapped surfaces of the nozzle valve and its body is necessary for lubrication. This leakage or overflow passes around the spindle and into the spring compartment. From here it is returned by overflow lines to the injection pump overflow valve.

d. Fuel supply and hand-primer pumps.

(1) General. The fuel transfer pump (fig 11-8) is mounted directly on the housing of the injection pump and is driven by the injection pump camshaft. It is a variable-stroke, self-regulating, plunger-type pump that will build pressure only up to a predetermined point. It includes a hand-operated stroke pump for priming the low-pressure fuel system.

(2) Operation (fig 11-9). As the injection pump cam allows the supply pump plunger to be forced by its spring toward the camshaft, the suction effect created opens the inlet valve and permits the fuel to enter the spring chamber. As the rotating cam lobe drives the plunger against its spring, the fuel inlet valve closes and the fuel is forced by the plunger through the outlet valve and around into the chamber created in back of the plunger by its forward movement. As the injection pump camshaft continues to rotate, it allows the compressed plunger spring to press the plunger backward again, forcing the fuel oil behind the plunger out into the fuel line leading to the secondary filter and the injection pump. At the same time, the suction-effect cycle is repeated. This pumping action continues as long as the fuel is being used fast enough by the injection pump to keep the supply pressure from rising to the point where it equals the force exerted by the spring on the plunger. The pressure between the supply pump and the injection pump holds the plunger stationary against the spring and away from the pump rod. This prevents further pumping action until the pressure drops enough to permit the plunger to resume operation. This entire cycle is automatic and it continues as long as the engine is running.

(3) Hand priming pump. The hand priming pump, attached to the supply pump at the inlet valve chamber, permits priming of the fuel injector pump by manually filling the low-pressure side of the injection system. Raising the pump handle creates a vacuum which in turn lifts the inlet valve off its seat and causes fuel to be drawn into the hand primer pump barrel. On the down stroke the inlet valve closes and fuel is pumped through the supply pump spring chamber to and through the outlet valve. Continued stroking of the priming pump will draw in fuel and pump it out through the low pressure lines to the injection pump. The hand priming pump must be used to purge the fuel system of air at any time a line is disconnected or a filter changed. It may also be used to assist timing of the injection pump.

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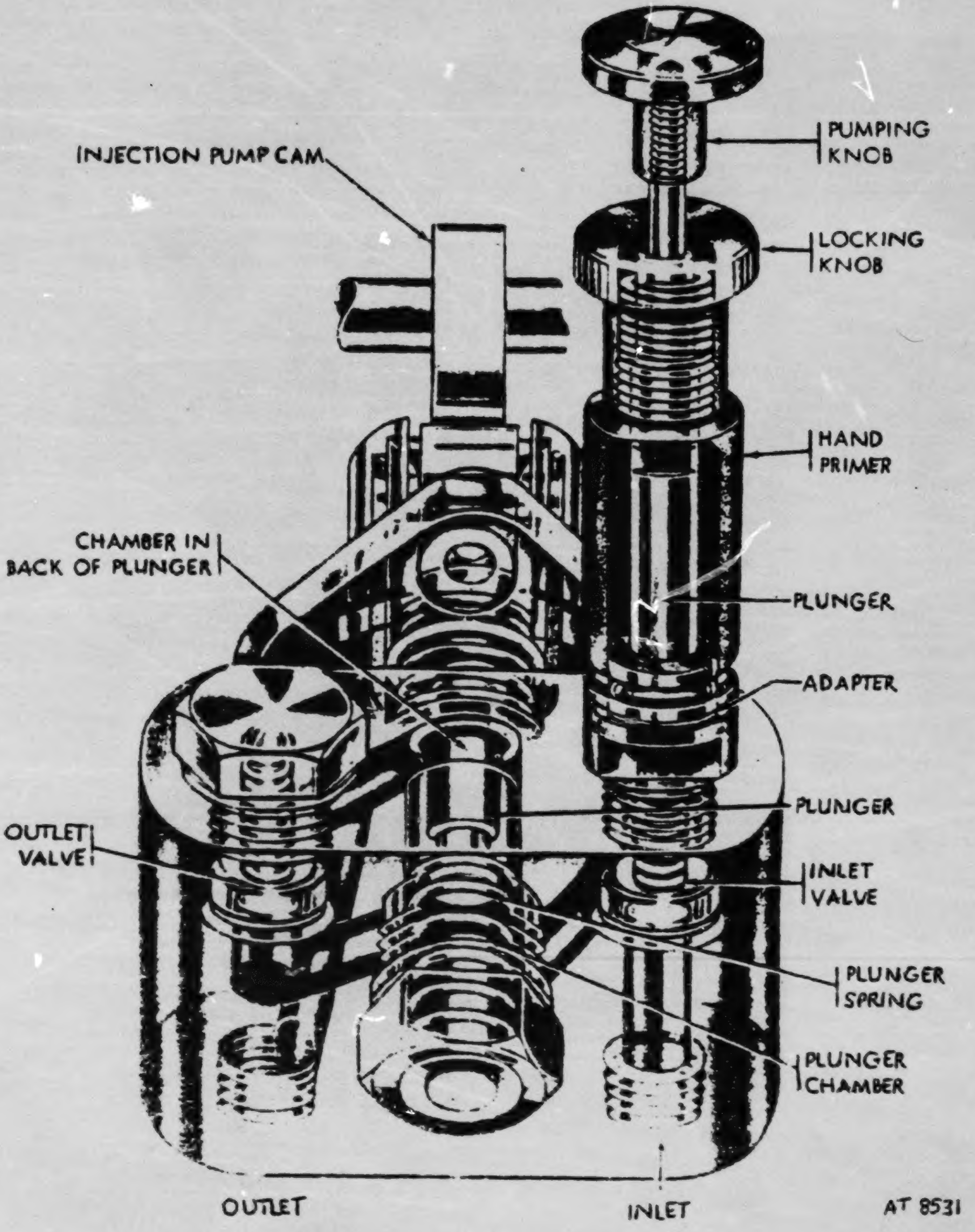
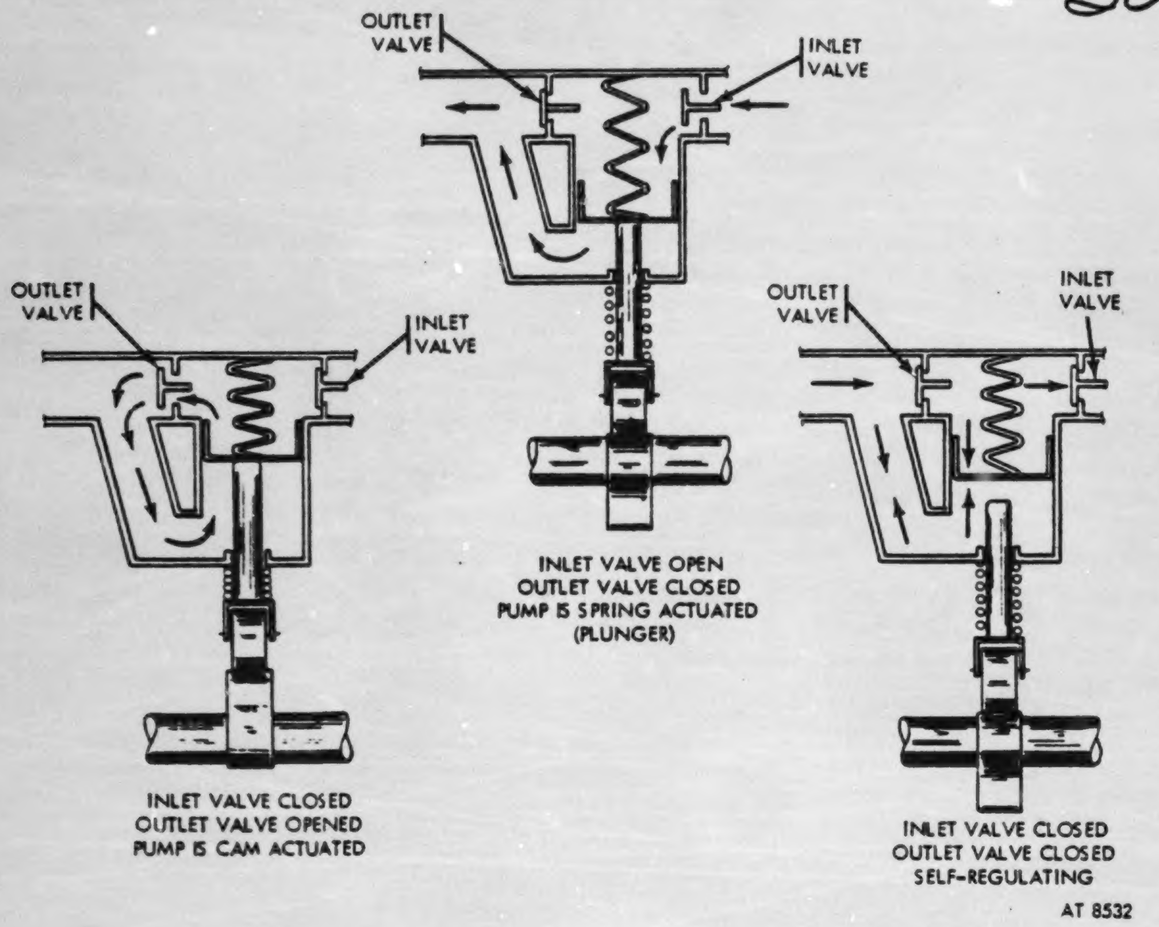

INJECTION PUMP CAM
PUMPING KNOB
LOCKING KNOB
HAND PRIMER
CHAMBER IN BACK OF PLUNGER
PLUNGER
ADAPTER
PLUNGER
OUTLET VALVE
INLET VALVE
PLUNGER SPRING
PLUNGER CHAMBER
OUTLET
INLET
AT 8531

Figure 11-8. Fuel transfer and hand-primer pump—cutaway view.



INLET VALVE CLOSED
OUTLET VALVE OPENED
PUMP IS CAM ACTUATED

INLET VALVE OPEN
OUTLET VALVE CLOSED
PUMP IS SPRING ACTUATED
(PLUNGER)

INLET VALVE CLOSED
OUTLET VALVE CLOSED
SELF-REGULATING

Figure 11-9. Schematic diagram illustrating operation of fuel supply pump.

e. Governor.

(1) **General.** All diesel engines require governors to prevent overspeeding of the engine under light loads. Vehicle diesel engines also require control of idling speeds. Since diesel engine speed is controlled by the amount of fuel injected, the injection system is designed to supply the maximum amount of fuel which will enable the engine to operate at full load and to reach a predetermined maximum speed (RPM). However, if the maximum fuel charge were supplied to the cylinders with engine operating at "PARTIAL LOAD" or "NO LOAD," the engine speed would increase beyond the critical operating range and cause premature failure or excessive wear. Thus, the governor must accurately control the amount of fuel injected to control the engine speed. The governor used with the Mack model ENDT 673 engine is of the mechanical or centrifugal flyweight type. The governor is gear-driven by the pump camshaft.

(2) Operation.

(a) The operation of the mechanical governor is based on the centrifugal force of rotating weights counterbalanced by springs. When the speed of the engine increases, the weights fly outward, pulling with them suitable linkage to change the setting of the injection pump control rod. The governor linkage is connected to the injection pump in such a manner that the spring moves the control mechanism toward the full-fuel position, and the action of the flyweights reduces the amount of fuel delivered.

(b) A typical variable speed governor is shown schematically in figure 11-10. With this type of governor, the operator varies the governor spring tension to control the quantity of fuel and does not at any time move the injector control rack directly. The control rack of the injection pump is connected to the yoke of the governor in such a manner that any movement of the yoke will directly affect the quantity of fuel injected. The spring tension is controlled by the operating lever, the movement of which is determined by the position of the foot throttle. The travel of the operating lever is limited by the idle- and maximum-speed screws. With the weights fully collapsed (engine stopped), the spring moves the sliding sleeve and yoke so that the fuel injection pump is in the full-fuel position. When the weights are fully extended, the sliding sleeve and yoke move to the rear and decrease the amount of fuel delivered.

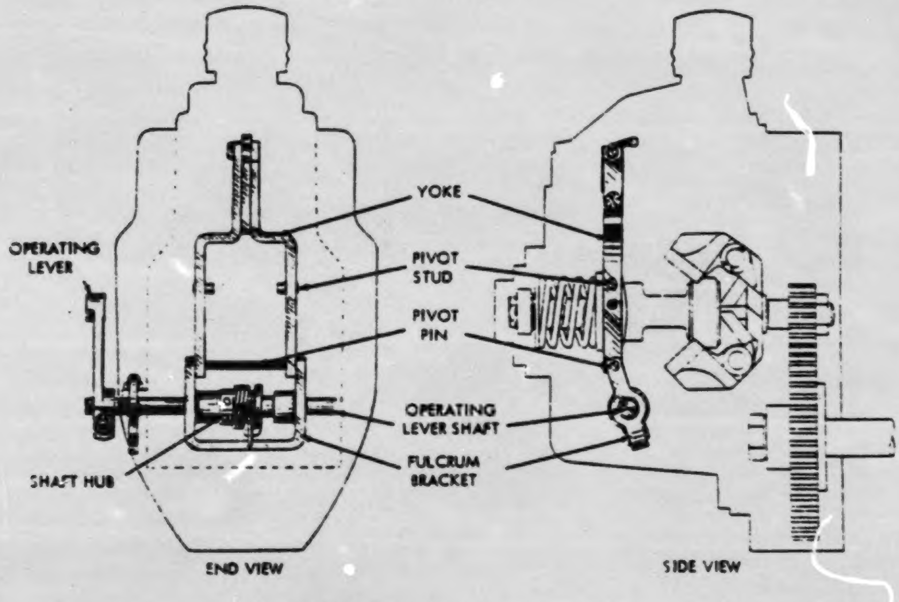


Figure 11-10. Mechanical governor—component locator.

(c) If the load on the engine is decreased, the engine tends to accelerate. However, when the engine accelerates, the governor flyweights move outward as a result of increased centrifugal force. Since the flyweights are in contact with the sliding sleeve assembly, this movement causes a longitudinal movement of the sleeve to the rear. This movement continues until an equilibrium is established between the governor spring force and the centrifugal force exerted by the flyweights. This occurs when the engine returns to the original speed determined by the position of the foot throttle and its effect on the governor spring.

(d) If the load on the engine increases, the engine tends to slow down, thereby causing an inward movement of the flyweights. As the weights move inward, resulting in reduced force on the sliding sleeve, the compressed governor spring shifts the sleeve to the front until the spring force and the centrifugal force exerted by the flyweights are again balanced. In this way, the yoke, following the movement of the sliding sleeve, moves the control rack of the fuel injection pump toward the more-fuel position and thereby returns the engine to the preset speed.

(e) To accelerate the vehicle, depress the foot throttle which, in turn, increases the spring tension. This causes the yoke to pivot to the rear, thereby increasing the supply of fuel. The flyweights move outward as a result of increased engine speed and prevent the control rack from reaching the full-fuel position unless the foot throttle is fully depressed. Deceleration is accomplished in the reverse manner. Spring pressure is decreased, the engine slows down, the flyweights move inward, and a balanced condition between the flyweights and the spring is obtained at a lower engine speed.

11-3. DESCRIPTION AND DATA.

a. Model differences.

(1) Injection pump, model APE 6BB90Q 5036A.

(a) Model 5036A injection pump is the original equipment furnished on Mack model ENDT 673 engine 11GBA 12006P1, FSN 2815-980-7092.

(b) Model 5036A injection pump includes model GVB 250/1050C 5037B governor.

(2) Injection pump, model APE 6BB90Q 5748A.

(a) Model 5748A injection pump is the original equipment furnished on Mack model ENDT 673 engine 11GBA 12006AP1, FSN 2815-087-2273 and 11GBA 12006BPI, FSN 2815-045-6865.

(b) Model 5748A injection pump includes model GVB 250/1050C 5479A governor.

(c) This pump is furnished with a spring-loaded operating lever. No additional accelerator retractor spring is required. With the spring lever, both the external fast and idle stopscrew stops are removed.

(3) Governor, model GVB 250/1050C 5037B.

(a) This governor shift is supported on two ball bearings. The weights have two needle bearings each.

(b) A splined drive gear and hub assembly driven by the injection pump camshaft is used to drive the governor.

(4) Governor, model GVB 250/1050C 5479A.

(a) This governor shaft is supported by one ball bearing and a Teflon bushing in the end cap. The weights are also Teflon-bushed.

(b) A slip clutch drive gear assembly driven by the pump camshaft is required for usage with the Teflon bushings.

b. **Interchangeability.** Either injection pump assembly may be installed on either engine as a complete unit. The Teflon governor cannot be used on model 5036A pump, nor can the metal bearing governor be used on the model 5748A injection pump, without changing the drive gear assembly and operating level. Hand-primer pumps and supply pumps are interchangeable.

c. **Data.**

(1) For 11GBA 12006P1 engine:

Injection pump

Manufacturer	American Bosch
Model.	APE 6BB90Q 5036A
Mack part number	313GC 4127
Plunger diameter.	9mm

Governor

Manufacturer	American Bosch
Model.	GVB 250/1050C 5037B
Mack part number	709GB 318
Nozzle holder opening pressure	2,300-2,350 PSI

(2) For 11GBA 12006 AP1 and 11GBA 12006 BP1 engine:

Injection pump

Manufacturer	American Bosch
Model.	APE 6BB90Q 5748A
Mack part number	313GC 4127A
Plunger diameter	9mm

Governor

Manufacturer	American Bosch
Model.	GVB 250/1050C 5479A
Mack part number	7096B 318A
Nozzle holder opening pressure	2,300-2,350 PSI

(3) Governed speed

Fuel load	2,100 RPM
No load	2,250 RPM
Operating range (most efficient)	1,500-2,000 RPM
Idling speed	550-575 RPM (min)

(4) Injection timing, port closing	29° BTC
(5) Fuel oil grade	2D

11-4. TESTS AND CALIBRATION.

a. General.

(1) All components of the fuel injection system must be tested and calibrated, or adjusted in a systematic method prior to installing on the engine. Since nozzles are required to test the pump, they must be tested first. The governor speed settings cannot be obtained until the injection pump fuel flow has been established.

(2) The nozzle holders and injection pump assembly are installed as a matched set on the original manufactured engine. Each nozzle holder carries the last three figures of the injection pump serial number. They are also numbered to show the cylinder location. By mating the proper nozzle holders with the correct pump and in proper order, results obtained on the calibration stand will be duplicated when installed on the engine. Failure to do this may result in an unbalanced fuel delivery.

b. Fuel transfer and hand-priming pump.

Note. - Key numbers in (1)(a) thru (d) below refer to figure 11-11 unless otherwise specified.

(1) Pressure test.

(a) Remove tappet shell pin (5), tappet assembly (29), and tappet spring (4) from fuel pump housing (6). To prevent loss of spindle during leakage test, insert a 1/8-inch diameter pin through the two holes in base of housing tappet guide.

(b) Close outlet side of pump with a 1/4-inch pipe plug. Connect fuel inlet of pump to fuel nozzle test stand. Pump test oil into pump to a pressure of 300 PSI. The minimum time for a pressure drop to 150 PSI is 10 seconds. Oil leakage will be evident at the open end of spindle bore. Also, at this time, check the inlet and outlet valves and plunger spring screw (23) for leaks.

(c) If excessive oil leakage is evident at the spindle, replace the spindle.

(d) Remove 1/8-inch diameter service pin from base of housing, tappet spring (4), and tappet assembly (29) in housing (6) and retain, using tappet shell pin (5). Stake the tappet shell pin (5) slightly at each end of pin.

(2) Operating test.

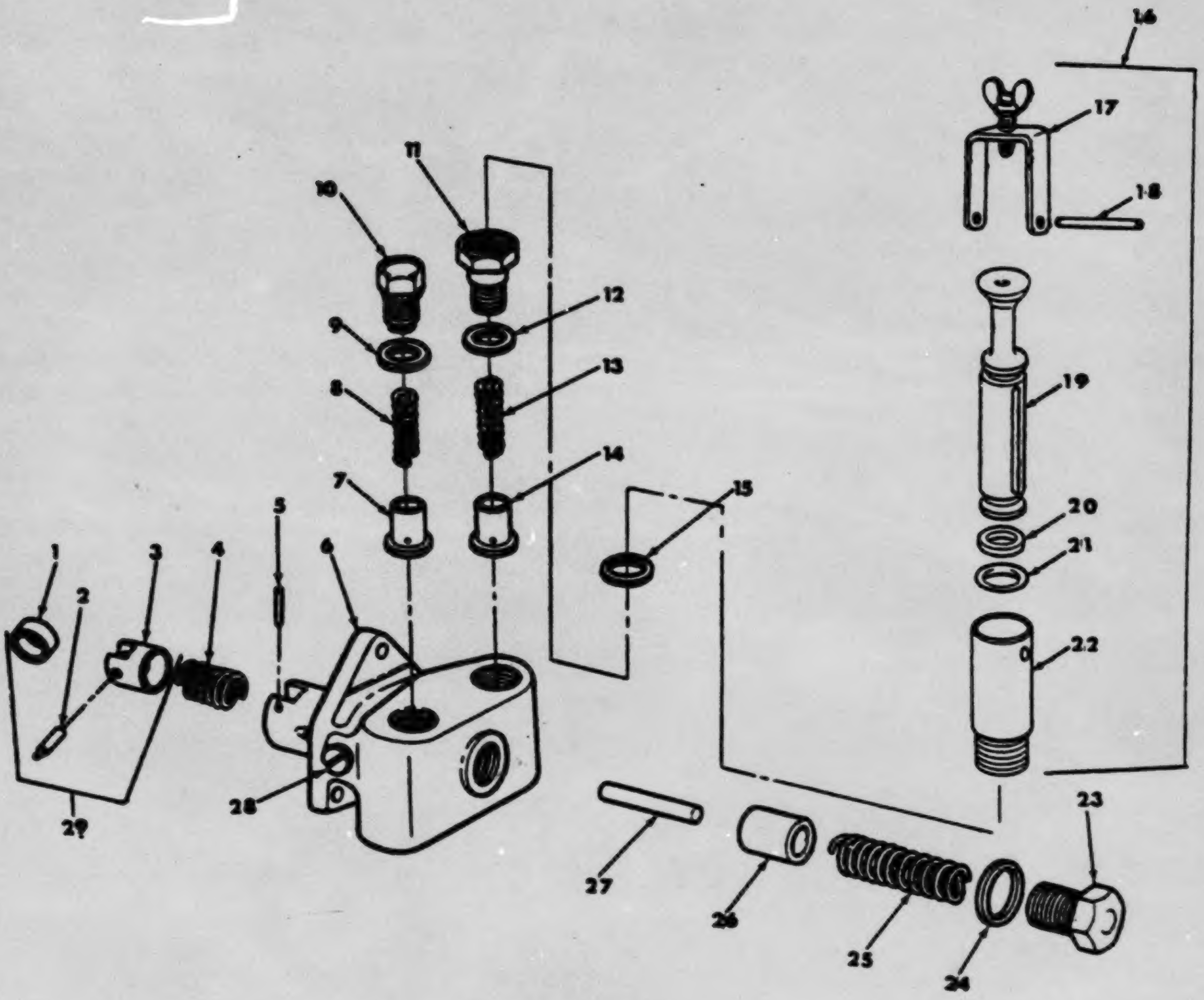
(a) The operating test is made with the fuel transfer pump and hand-priming pump installed on the injection pump mounted in the calibration stand.

(b) Connect test stand fuel tank to pump inlet port. Install a 0-60 PSI pressure gage in the return line. Operate test stand.

(c) Fuel transfer pump must deliver 20 PSI or greater pressure.

Note. - In the absence of pressure, the pump may be air-locked. Loosen the outlet valve spring retaining screw sufficiently to bleed out all air. Retighten screw.

(d) With the fuel injection pump at rest, drain fuel lines and reconnect. Stroke hand primer until fuel flows. If more than 30 strokes are required or if stem leaks, replace piston packings.



AT 8537

1	Tappet shell roller
2	Tappet roller pin
3	Tappet shell
4	Tappet spring
5	Tappet shell pin
6	Fuel pump housing
7	Valve
8	Valve spring
9	Retaining screw gasket
10	Valve spring screw
11	Handpump adapter
12	Adapter gasket
13	Valve spring
14	Valve
15	Plunger gasket
16	Hand primer pump
17	Bracket assembly
18	Cross pin
19	Plunger
20	Knob sealing washer
21	Plunger preformed packing
22	Barrel
23	Plunger spring screw
24	Plunger screw gasket
25	Plunger spring
26	Plunger
27	Tappet shell spindle
28	Pipe plug
29	Tappet assembly

Figure 11-11. Fuel transfer and hand-priming pump—exploded view.

(3) Testing hole-type nozzles.

Warning. - The penetrating power of atomized oil under pressure is sufficient to puncture the skin and may cause blood poisoning. Therefore, hands must be kept away from a spraying nozzle.

(a) Attach nozzle holder assembly to correct size test stand (fig 11-12). Close the pressure gage valve to protect the gage and actuate the test stand lever rapidly (about 25 strokes per minute) to expel air from the nozzle and holder and to "settle" the spring and nozzle loading column. Open the pressure gage valve one-half turn and depress the operating lever slowly to raise pressure. Observe nozzle opening pressure on gage. If opening pressure is other than 2,300 PSI, adjust to correct setting.

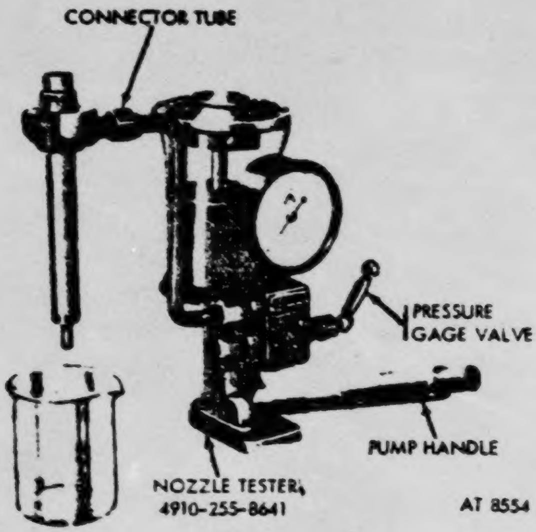


Figure 11-12. Nozzle test stand.

Note. - Protection cover must be removed and locknut loosened prior to making adjustment. When adjusted, secure locknut.

(b) When a new pressure-adjusting spring is used, adjust the opening pressure 10 percent higher than specification to allow for spring set.

(c) Actuate the operating lever slowly to build up pressure, and as the correct opening point is approached, observe the spray orifice of the nozzle. If drops of fuel form or oil issues as a stream at pressures 100 PSI below the opening pressure, the nozzle is leaking and must be replaced.

(d) If the assembly passes the leakage test without leaking, the spray pattern should be examined. Close the gage valve to protect the gage when lever of test stand is actuated rapidly.

Note. - Make sure that all holes are open and appear to be spraying the same quantity of fuel.

(e) Operate lever at a rate of approximately 15 strokes per minute. The spray formation should be sharp with a rather solid pattern, and the angles formed by the individual sprays should be uniform (fig 11-13).

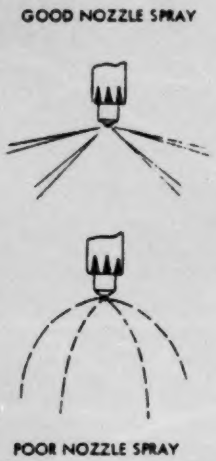


Figure 11-13. Nozzle spray patterns: Top—good nozzle spray; lower—poor nozzle spray.

(f) Usually the spray of a hole-type nozzle will be satisfactory if the valve seat is tight, valve free, and all spray orifices clean. However, if the nozzle is not in good operating condition, the spray pattern will be poor (fig 11-13). If the spray pattern cannot be corrected, the nozzle should be replaced.

(g) The nozzle chatter must be distinct and regular. A sharp, pitched sound is not mandatory, and an occasional skip or variation in the chatter pitch sound is acceptable.

(h) The "chatter" test requires that the stroke of the test handle takes approximately two seconds. This must be performed with the test stand pressure gage out of the line (valve shut off).

(4) Internal timing.

(a) Whenever a fuel injection pump has been completely disassembled and reassembled, it is necessary that both internal timing and calibration of the pump be checked even though none of the components were replaced. Internal timing for the Mack ENDT 673 engine injection pump is timed for port closing, or the upper end of the plunger completely covers the fuel inlet holes in the barrel and no fuel flows from the delivery valve. Each delivery valve must close 60°, plus or minus 1/2°, apart in firing order sequence, to be properly timed.

(b) To time an injection pump, a test stand equipped with a coupling having a 360° protractor and pointer (FSN 4910-981-2770) is required to check the 60° intervals. In addition, a dial indicator and modified delivery valve holder is required to check plunger lift to cutoff point. Enlarge delivery valve holder bore to 0.156 inch.

(c) Assemble pump to test stand, using flange adapter FSN 4910-981-2771 (fig 11-14). Block operating lever in full open position. Remove side inspection cover. Remove No 1 delivery valve holder and nut. Also remove delivery valve spring and needle. Needle may be easily removed by pumping fuel to lift the needle from the valve. Install modified delivery valve holder and nut. Carefully insert 0.125-inch diameter rod through hole until it rests on plunger. Rod must be 3-1/2 inches or longer. Assemble dial indicator to read stroke, and set dial at zero for lowest portion of stroke (fig 11-15).

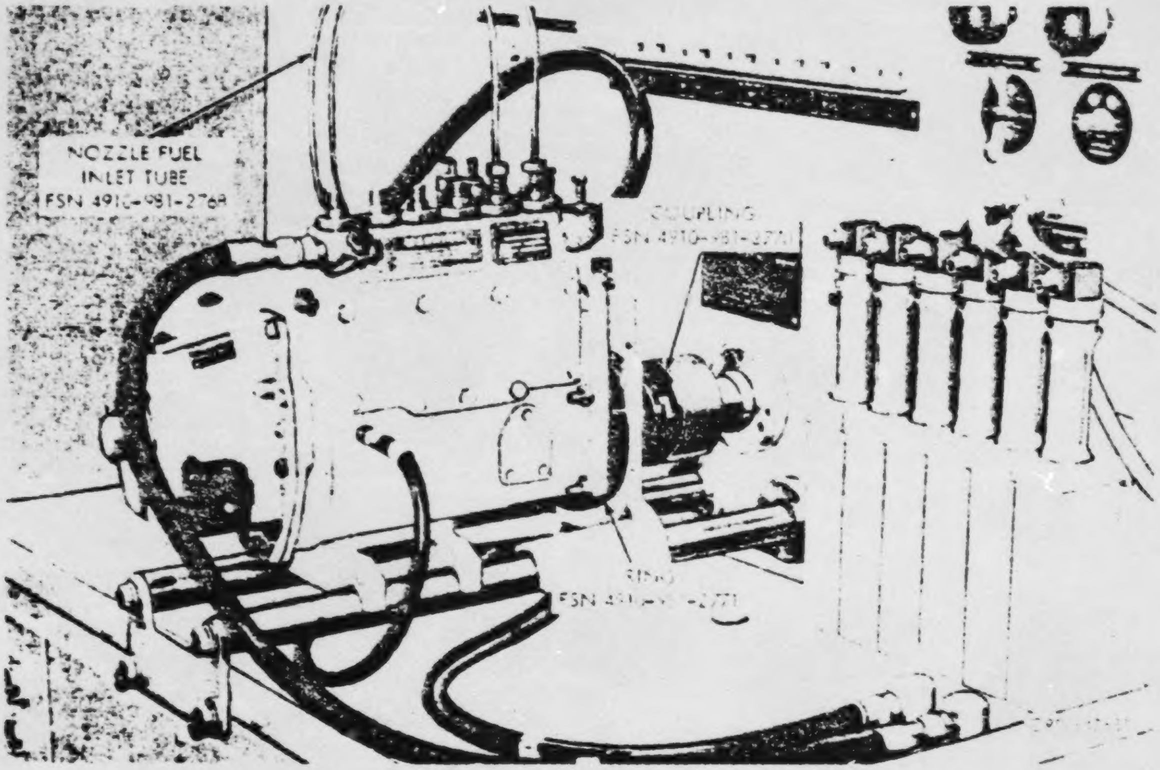


Figure 11-14. Fuel injection pump assembly mounted on test stand.

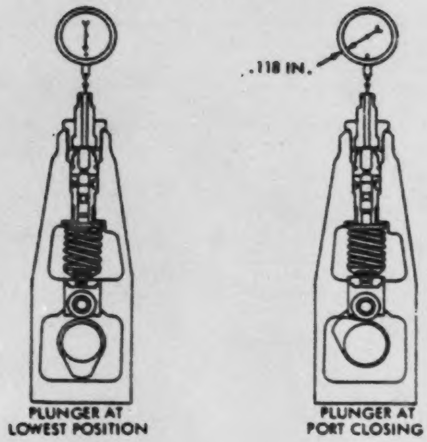


Figure 11-15. Port-closing dial indicator.

Note. - The delivery valve needle is a lapped and mated part to the valve body. Do not handle the lapped surfaces.

(d) Provide for fuel flow by hand supply pump, gravity feed, or test stand pump. Attach fuel line to injection pump. Fuel should flow from No 1 delivery valve. Rotate pump in a clockwise direction, when viewed from front, until fuel flow ceases. Wipe fuel from holder to better observe fuel action. Fuel will cease the instant the plunger covers the fuel inlet port. Read dial indicator.

(e) If no timing spacers are in the pump, the reading will be greatly above specifications. Spacers are not always inserted at the time of pump rebuilding. Timing spacers are obtainable in 0.050-, 0.054-, 0.058-, 0.062- and 0.066-inch thicknesses. When properly timed, fuel will cease when plunger rises 0.118 inch, plus 0.010 inch, minus 0.004 inch.

(f) Using plunger spring compressor (FSN 4910-977-7419), rotate camshaft to lower tappet and compress spring. Using two narrow screwdrivers, raise tappet knob and insert proper tappet spacer under knob. Remove spring compressor.

(g) Repeat test, setting dial indicator at zero for low point. Fuel should cease at specified stroke. If not, replace spacer with thicker or thinner spacer.

(h) When No 1 delivery valve port closing is correct, set indicator on test stand protractor at 0° at point of port closing. Remove dial indicator, test rod, and modified delivery valve holder. Carefully replace delivery valve needle and spring. Replace delivery valve holder and nut. Torque to 85-90 lb-ft.

(i) Proceed to time remaining delivery valves in firing order sequence of 1-5-3-6-2-4. Test stand indicator should be 60°, ± 30', at point of port closing. Each additional valve must be timed to a multiple of 60°, ±30'.

(j) After timing all delivery valves, check plunger for bottoming on delivery valve by rotating camshaft until No 1 plunger is at highest position. Using narrow screwdriver, pry up on plunger. Plunger must be free to move. If plunger is against delivery valve, retime pump, using thinner spacer.

SECTION XII. CUMMINS FUEL SYSTEM

12-1. GENERAL. The NHC-250 Cummins engine (fig 12-1) is new to the Army inventory. The PT (pressure-timed) fuel system is based on the principle that the volume of liquid flow is proportional to the fluid pressure, the time allowed to flow, and the size of the passage the liquid flows through.

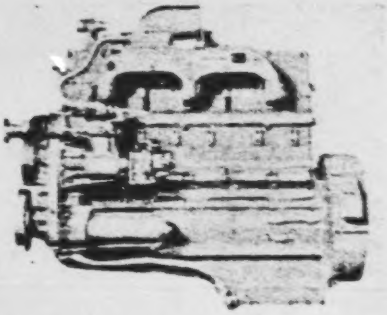


Figure 12-1. NHC-250 engine model.

12-2. FUEL SYSTEM - BASIC OPERATION. The fuel system (fig 12-2) is composed of one fuel tank with a vented filler cap and delivery and return lines going to the fuel supply pump from the cylinder heads. Flexible lines connect the tank to the pump. Rigid lines connect the pump to drilled fuel supply passageways in the cylinder head. These passages deliver fuel to the (PTD) injectors which are the unit type. Mounted between the fuel tank and the fuel supply pump is one disposable type cartridge fuel filter. The PT fuel supply pump is manufactured by the Cummins Engine Company and is the pressure-timed type. The pump is gear driven at engine speed and mounted on the left side of the engine. The PT (type G) ~~fuel~~ pump can be identified by the absence of the return line at the top of the fuel pump. The fuel pump has four main components.

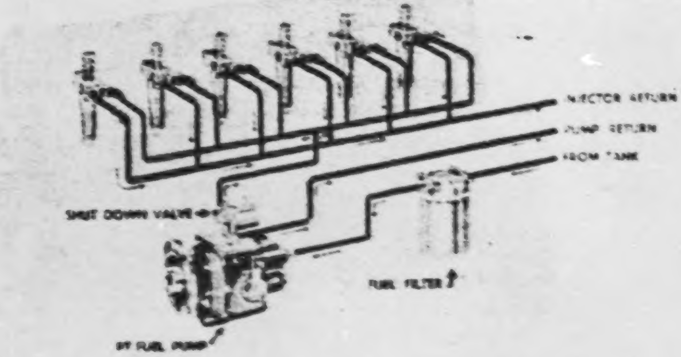


Figure 12-2. PT fuel system - fuel flow diagram.

a. The gear pump (fig 12-3) draws fuel from the supply tanks and forces it through the pump filter screen to the governor. It is driven by the pump main shaft and contains a single set of gears to pick up and deliver fuel throughout the fuel system. A pulsation damper mounted to the gear pump contains a steel diaphragm which absorbs pulsations and smooths fuel flow through the fuel system. From the gear pump, fuel flows through the filter screen to the governor screen. The PTG pumps are equipped with a bleed line which is attached to the engine injector return line, or to the tank, and prevents excessive fuel temperature within the fuel pump. The bleed line functions primarily when the pump throttle is set at idle speed, but gear pump output is high due to engine operating speed as occurs at downhill operation. A special check valve and/or fitting is used in the gear pump to accomplish the bleed action.

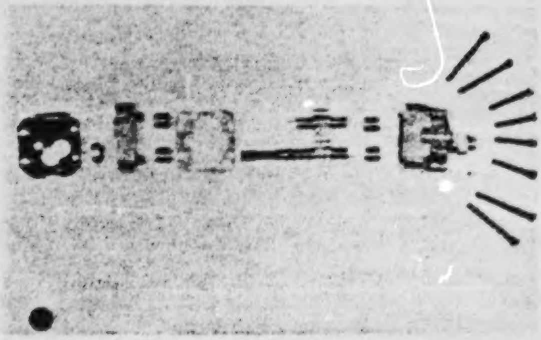


Figure 12-3. Gear pump.

b. The governor controls the flow of the fuel from the gear pump, as well as the maximum and idle speeds. The mechanical governor is actuated by a system of springs and weights and has two functions. First, the governor maintains sufficient fuel for idling with the throttle control in idle position; second, it cuts off fuel to the injectors above maximum rated RPM. The idle springs (in the governor spring pack) position the governor plunger so the idle fuel port is opened enough to permit passage of fuel to maintain engine idle speed. During operation between idle and maximum speeds, fuel flows through the governor to the injector in accordance with the engine requirements, as controlled by the throttle and limited by the size of the idle spring plunger counterbore on the PTG fuel pumps. When the engine reaches governed speed, the governor weights move the governor plunger, and fuel passages to the injectors are shut off. At the same time, another passage opens and dumps the fuel back into the main pump body. In this manner, engine speed is controlled and limited by the governor regardless of throttle position. Fuel leaving the pump flows through the shutdown valve, inlet supply lines, and into the injectors.

c. The throttle provides a means for the operator to manually control engine speed above idle as required by varying operating conditions of speed and load. In the PTG pump, fuel flows through the governor to the throttle shaft. At idle speed, fuel flows through the idle port in the governor barrel, past the throttle shaft. To operate above idle speed, fuel flows through the main governor barrel port to the throttling hole in the shaft.

d. The fuel shutdown valve (fig 12-4) is located on top of the fuel pump. It shuts off fuel to the injectors. With the master switch on, the solenoid opens the valve. With the switch off, the spring-loaded valve returns to the OFF position. In case of an electrical failure, rotate the manual knob clockwise to permit fuel to flow through the valve. The knob is located on the front of the valve.

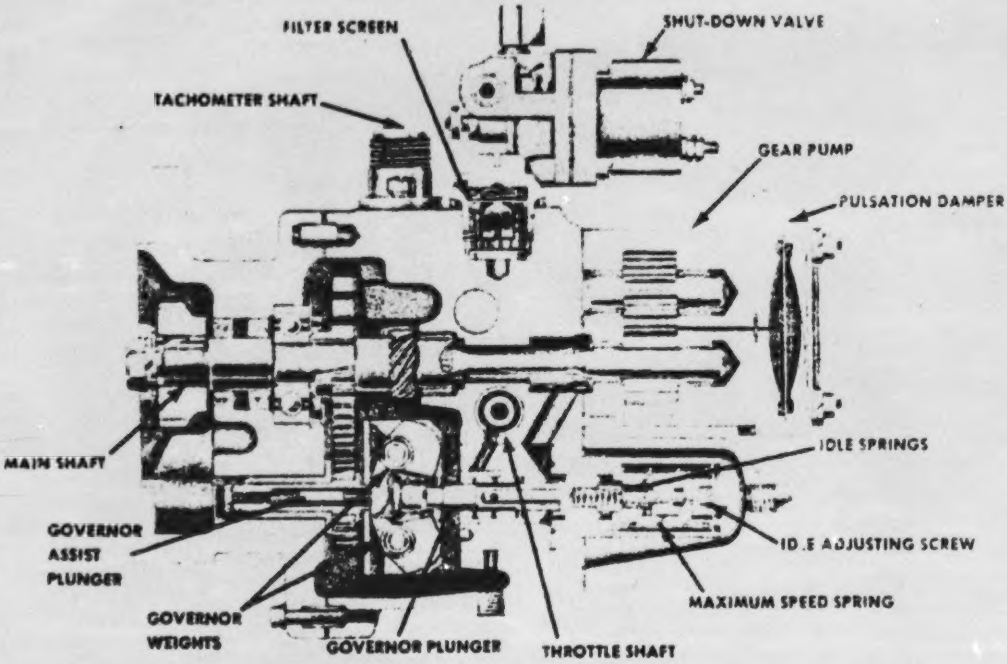

FILTER SCREEN
SHUT-DOWN VALVE
TACHOMETER SHAFT
GEAR PUMP
PULSATION DAMPER
MAIN SHAFT
IDLE SPRINGS
GOVERNOR ASSIST PLUNGER
IDLE ADJUSTING SCREW
MAXIMUM SPEED SPRING
GOVERNOR WEIGHTS
GOVERNOR PLUNGER
THROTTLE SHAFT

Figure 12-4. Cross section, PTG fuel pump.

12-3. POSITIVE DISPLACEMENT FUEL PUMP. This pump contains a drive gear and shaft which is splined to the main drive shaft. An idler gear is located toward a bleed-off passage and check valve fitting. It is important that the correct restriction fitting is utilized to insure integral gear pump cooling. A locating notch on the pump body and cover is used for assembly and determination of pump rotation.

12-4. MECHANICAL MAXIMUM SPEED GOVERNOR. This is sometimes called an "automotive governor" and is a limiting speed type. It is actuated by a system of springs and weights and has two functions. First, the governor maintains sufficient fuel for idling with the throttle control in idle position. Second, it cuts off fuel to the injectors above maximum rated RPM. The idle springs, in the governor spring pack, position the governor plunger so the idle fuel port is opened enough to permit passage of fuel to maintain engine idle speed. A governor plunger, guided by a barrel, operates between the toes of the governor weights and the governor spring pack. A weight-assist plunger exerts some pressure against the governor plunger to stabilize the governor action in the lower RPM range.

12-5. MECHANICAL VARIABLE SPEED GOVERNOR (MVS) (FIG 12-5). This supplements the standard automotive governor. The automotive type governor cannot be expected to regulate engine speed below full-load speed and when trying to regulate engine speed by reducing the throttle position; a slight variation in load from the power takeoff-driven equipment will cause a varying engine speed. For all applications in which the engine is driving the power takeoff equipment, and at the same time the operator is not controlling the engine speed by maintaining a constant touch with the throttle, a variable speed governor must be utilized. A typical application is found on the M816 wrecker. The MVS governor assembly mounts on top of the fuel pump, and the fuel solenoid is mounted to the governor housing. The governor also may be remote mounted. Fuel from the fuel pump body enters the variable speed governor housing and flows to the governor barrel and plunger. Fuel flows past the plunger to the shutdown valve and into the injector, according to governor lever position (as determined by the operator). The variable speed governor CANNOT produce engine speeds in excess of the automotive governor setting. Speeds below idle setting may be obtained; however, adjustment settings should not be made for less than automotive idle speed. On engine applications requiring a preset MVS governor, an air-actuated cylinder is available. This cylinder has a preset 1-inch stroke and is mounted to the governor in a position to push upon the governor throttle lever. A shorter lever should be used with the air cylinder to avoid problems with travel length, RPM range, and alinement. An air line under a minimum of 60 PSI, with a 1/8" NPT, is required to hook up and activate the governor. Calibration procedures are similar to regular pump testing with the exception of certain specifications.

12-6. NOZZLE IDENTIFICATION (FIG 12-6).

a. The PT injection system is used on Cummins engines only.

b. The system uses mechanically operated unit injectors and a variable pressure fuel supply pump.

c. The letters PT that identify both the pump and the system signify pressure-time and refer to the method of metering the fuel.

(1) Looking at an injector assembly, you will notice markings on the plunger, injector adapter, and injector cup. These markings are important for matching parts and testing procedures.

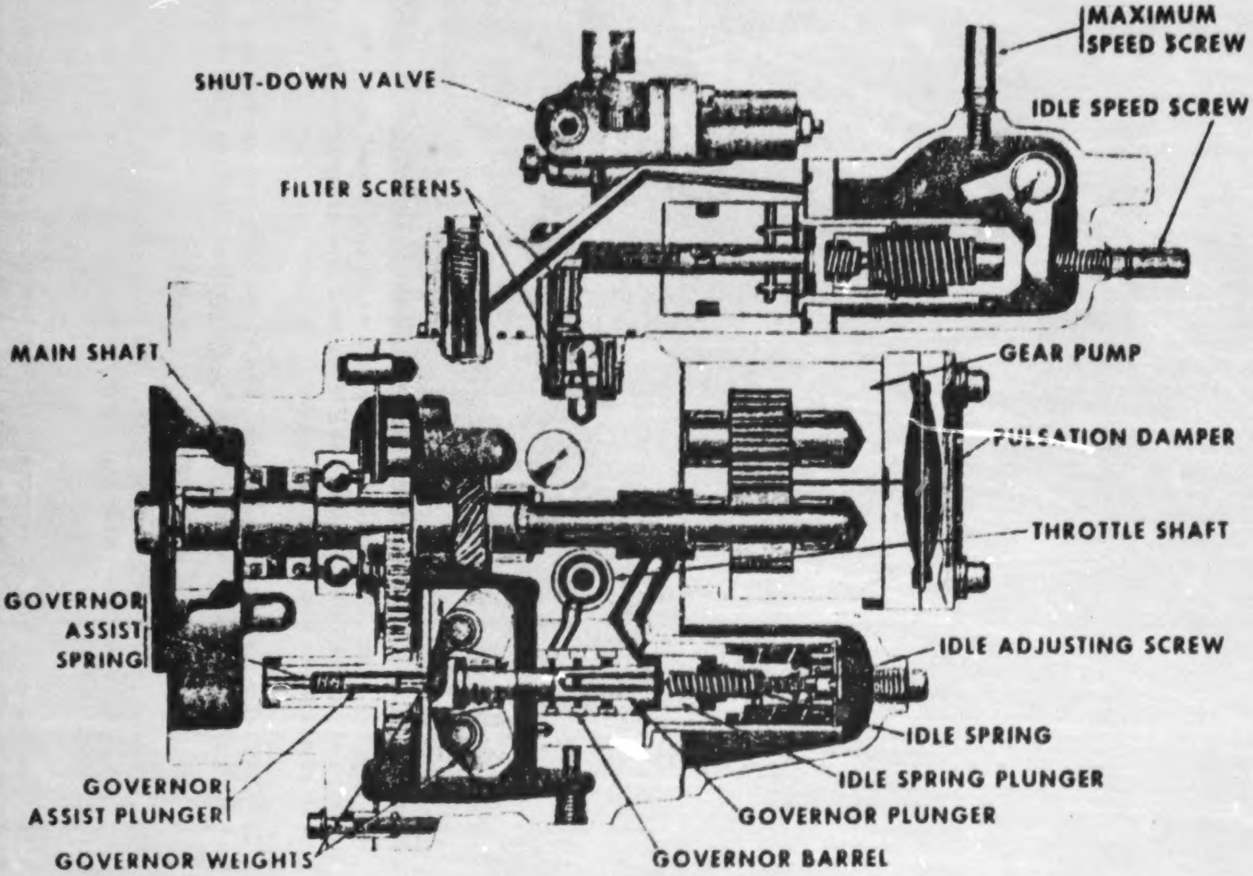
(2) Plunger - date, feed orifice size, and class fit.

(3) Injector adapter - cup hole size and flow code.

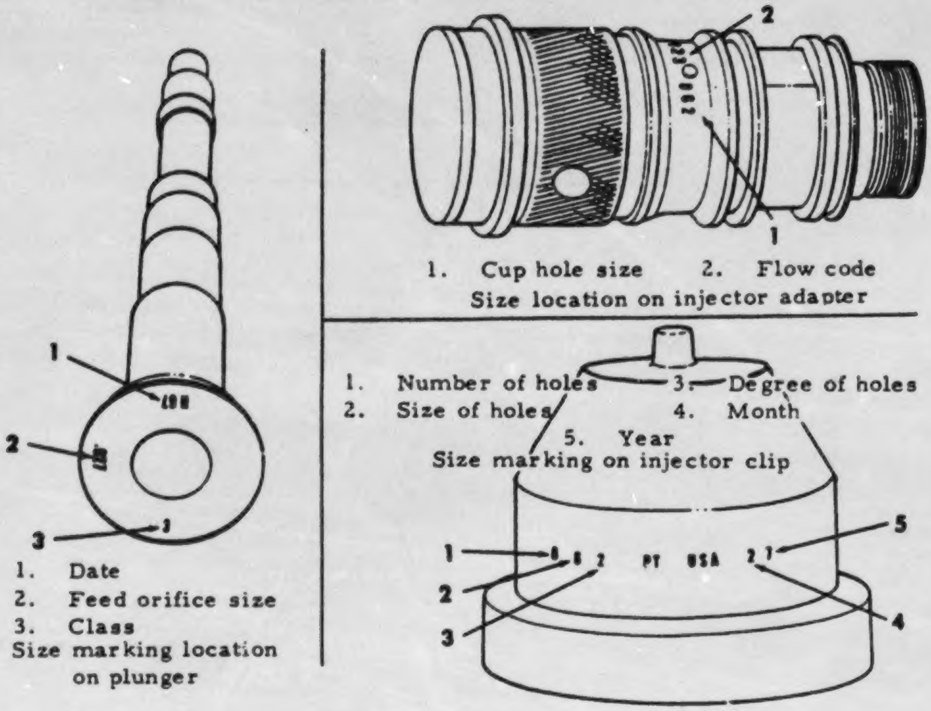
(4) Injector cup - number of holes, size of holes, degree of holes, and date (month and year).

PTG FUEL PUMP / MVS GOVERNOR CROSS SECTION

CUMMINS NHC-250 ENGINE


MAXIMUM SPEED SCREW
SHUT-DOWN VALVE
IDLE SPEED SCREW
FILTER SCREENS
MAIN SHAFT
GEAR PUMP
PULSATION DAMPER
THROTTLE SHAFT
GOVERNOR ASSIST SPRING
IDLE ADJUSTING SCREW
IDLE SPRING
IDLE SPRING PLUNGER
GOVERNOR ASSIST PLUNGER
GOVERNOR PLUNGER
GOVERNOR WEIGHTS
GOVERNOR BARREL

12-5. Mechanical variable speed governor.



1. Cup hole size 2. Flow code
Size location on injector adapter

1. Number of holes 3. Degree of holes
2. Size of holes 4. Month
5. Year
Size marking on injector clip

1. Date
2. Feed orifice size
3. Class
Size marking location on plunger

Figure 12-6. Injector markings.

12-7. CONSTRUCTION OF INJECTORS (FIG 12-7).

a. Description.

(1) **Injector body.** The injector body is a centrally bored body that serves as a housing to which all of the injector parts are lap-fitted into or attached to. The body has drilled fuel inlet passages and outlet passages.

(2) **Cup.** The cup screws onto the base of the body and serves as a storage area for the fuel during the metering phase. It has eight drilled orifices that the fuel is injected through.

(3) **Adjustable delivery orifice plug.** The plug screws into the main body. The orifice may be enlarged to allow more fuel into the injector. A screen covers the plug for final filtering of the fuel.

(4) **Check ball.** The small steel ball that moves to seal off incoming fuel at the end of the metering phase. The ball and stop may be replaced without replacing the main body.

(5) **Injector spring.** The spring returns the plunger to the up position. It is lapfitted to the body and has an annular groove that permits fuel to flow through the injector and back to the tank for cooling purposes.

CUMMINS NHC-250 ENGINE

1 CUP
2 CUP RETAINER
3 BARREL
4 PLUNGER
5 CHECK BALL
6 GASKET
7 CLIP
8 SCREEN
9 FUEL IN
10 ORIFICE
11 ORIFICE GASKET
12 COUPLING
13 ADAPTER
14 SPRING
15 LINK
16 FUEL OUT
17 'O' RING
18 NUT
19 ROCKER LEVER
20 ADJUSTING SCREW
21 PUSH ROD
22 TAPPET
23 CAMSHAFT LOBE

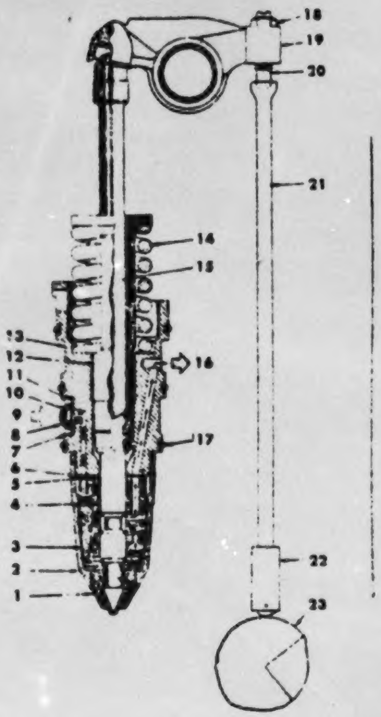


Figure 12-7. PTD injector—construction.

b. **Operation.** Fuel flows from a connection at the top of the fuel pump shutdown valve through a supply line into the lower drilled passage in the cylinder head at the front of the engine. A second drilling in the head is alined with the upper injector radial groove to drain away excess fuel. A fuel drain at the flywheel end of the engine allows return of the unused fuel to the fuel tank.

12-8. PHASES OF OPERATION (FIG 12-8).

a. **Metering.** This phase begins with the plunger just beginning to move downward and the engine on the beginning of the compression stroke. The fuel is trapped in the cup, the check ball stops the fuel from flowing backwards, and the fuel begins to be pressurized. The excess fuel flows around the lower annular ring, up the barrel, and is trapped there.

b. **Preinjection.** The plunger is almost all the way down, the engine is almost at the end of the compression stroke, and the fuel is being pressurized by the plunger.

c. **Injection.** The plunger is almost all the way down, the fuel is injected out the eight orifices, and the engine is on the very end of the compression stroke.

d. **Purging.** The plunger is all the way down, injection is finished, and the fuel is flowing into the injector, around the lower annular groove, up a drilled passageway in the barrel, around the upper annular groove, and out through the fuel drain. The cylinder is on the power stroke. During the exhaust stroke, the plunger moves up and waits to begin the cycle all over again.

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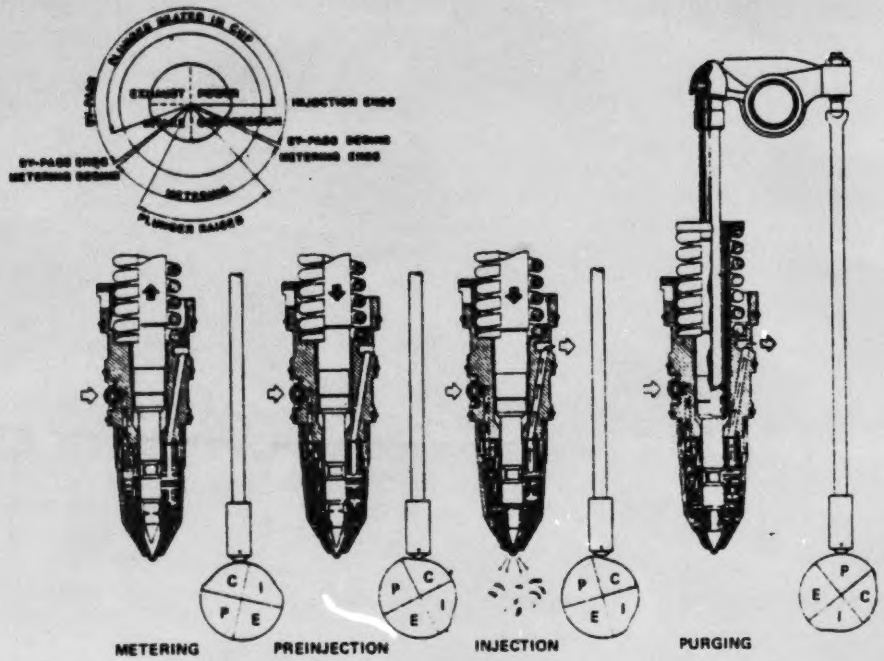

Figure 12-8. Phases of operation.

12-9. CALIBRATION OF CUMMINS FUEL INJECTOR NOZZLES USING THE FLOW COMPARATOR MODEL 67-7057.

a. The Bacharach model 67-7057 comparator (fig 12-9) is a bench-type comparator. It is designed to calibrate and flow test the Cummins PT and GMC unit injectors. The comparator is a self-contained unit, operating from a 115-volt AC, single-phase, 60-cycle power supply outlet, intended for mounting on a suitable frame or bench.

b. The comparator incorporates a motor-driven cam box, hydraulic ram cylinders, a hydraulic system, injector fuel system, and instrumentation required for flow testing the Cummins PT and GMC unit injectors. All major components are conveniently mounted on the instrument panel and on the base plate which is also the fuel tank cover. The fuel tank holds 10 gallons. In order to maintain constant calibrating oil temperature, a heat transfer is built into the fuel tank.

c. The comparator is supplied with basic accessories for mounting and testing the Cummins PT and GMC unit injectors (fig 12-10). The injector to be tested is placed in an inverted position between a suitable discharge head and the appropriate size pusher rod extension (fig 12-11). It is clamped with a predetermined force by a hydraulic ram cylinder. The cylinder is actuated by fuel pressure supplied by a motor-driven fuel pump. The cam box includes a two-lobe cam. One lobe is for driving the Cummins PT injector; the other is for Detroit Diesel 53 and 71 series unit injectors. The cam lobes are contoured to simulate exact engine operating conditions. The cam box may be driven at two different speeds merely by shifting the V-belt from one pulley to the other. The speed may be further changed by loosening the setscrew of the adjustable pulley and moving the pulley away from the motor to increase the speed, or moving the pulley toward the motor to decrease the speed.

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d. Each comparator is fully tested and calibrated at the factory prior to its shipment, using the Cummins master injector ST768 and those representing each major injector category.

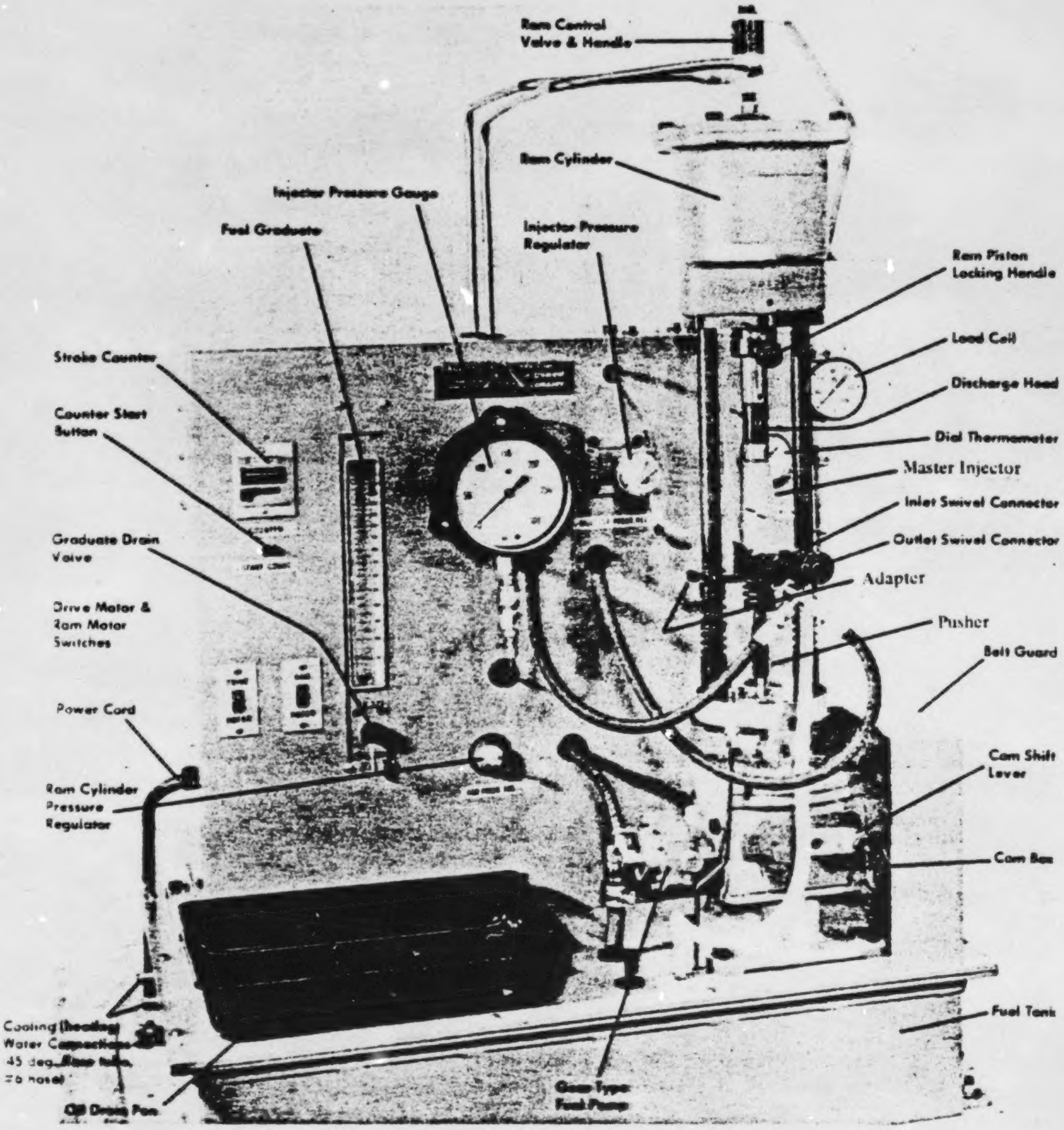
Ram Control
Valve & Handle
Ram Cylinder
Injector Pressure Gauge
Fuel Graduate
Injector Pressure
Regulator
Ram Piston
Locking Handle
Load Cell
Discharge Head
Dial Thermometer
Master Injector
Inlet Swivel Connector
Outlet Swivel Connector
Adapter
Pusher
Belt Guard
Cam Shift
Lever
Cam Box
Fuel Tank
Stroke Counter
Counter Start
Button
Graduate Drain
Valve
Drive Motor &
Ram Motor
Switches
Power Cord
Ram Cylinder
Pressure
Regulator
Cooling (heating)
Water Connections
45 deg. Elbow tube
76 hose)
Oil Drain Pan
Gear-Type
Fuel Pump

Figure 12-9. Comparator model 67-7057 with Cummins master injector ST768 installed.

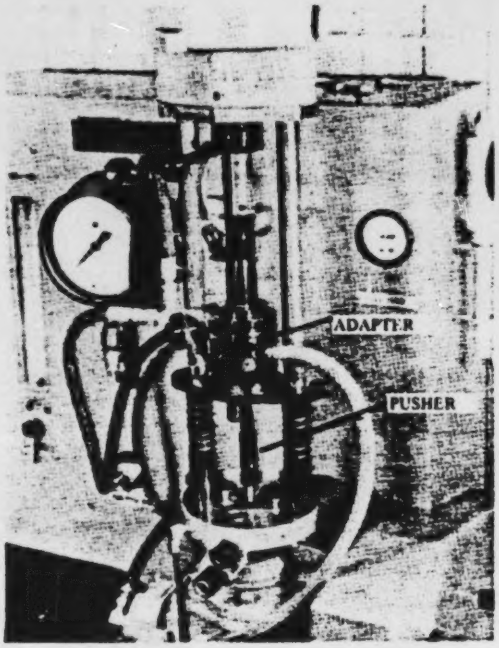

Figure 12-10. Comparator accessories.

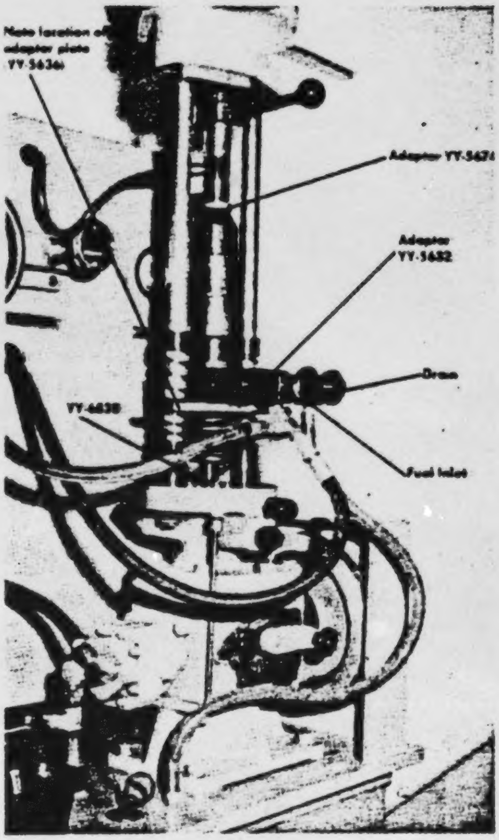

Figure 12-11. Cummins L-injector mounted on comparator.

12-10. MOUNTING THE PTD INJECTOR IN COMPARATOR.

a. Lubricate the internal surfaces of the adapter body and injector O-rings with Lubriplate.

b. Back out, or remove, the knurled locating screw from the adapter body. Remove clip and inlet screen from the side of the injector if installed.

c. Aline the injector delivery orifice with the locating screw hole in the adapter body. Press injector with hard pressure only into the adapter body until it bottoms.

d. Insert and tighten the locating screw into the adapter and look down from the top of the adapter to see that the locating screw extended into the injector.

e. Engage adapter body with injector into the adapter plate (YY-6824, JC, side up) and mount it in an inverted position on the comparator, using pusher rod No 67-1071.

f. While holding this assembly with one hand, operate the ram motor. Center the injector cup under the discharge head. Place ram control valve handle in "press" position.

g. After the ram piston with the discharge head has clamped the injector in place, wait 15 seconds and mechanically lock the piston by moving the locking handle forward. Then place the ram control valve handle in "lock" position and switch off ram motor.

h. Attach swivel connectors to adapter body. The inlet port is the one nearest the injector cup.

12-11. FLOW TESTING THE PTD INJECTOR.

a. Before regular flow testing of the injectors may be started, the comparator must be calibrated using the Cummins master injector No ST768. The Cummins master injector must always be tested with the 0.013-inch orifice installed and the cam shift lever in the "cam" position.

b. Mount the master injector (it is a flanged type) into the correct adapter plate, No 5630, so that the plate dowels engage into the injector flange holes.

c. Grasp with one hand the injector and adapter plate so that the plunger and link cannot drop and place the whole assembly in an inverted position between the guide posts. The plunger link must rest against the pusher rod extension, and the slots in the adapter. plate must engage the two guide posts over the two spacers. Make sure that the injector fuel inlet and outlet ports are positioned so that the inlet and outlet swivel connector can be easily attached from the operator's side.

d. While holding this assembly with one hand, operate the ram motor and with the locking handle, lock in position. Turn ram motor switch off.

e. Attach inlet and outlet swivel connectors to injector. The flange injector requires two reducer adapters.

f. The operating test fuel oil temperature must be 80° F to 100° F. Adjust the injector inlet pressure with the pressure regulator to read exactly 120 PSI. Run comparator for approximately 30 seconds to purge the air that may be in the system.

g. Set counter to 1,030 strokes. This is done by raising red lid while depressing black reset button and turning the individual digit wheels to the desired number of strokes. Now push the counter button and collect oil in the graduate.

h. Take a total of three readings and find the average. If the volume is below 132 cc, increase counter setting (use more strokes). If the volume is above 132 cc, decrease the counter setting. A change of 15 strokes will result in a volume change of about 2 cc.

i. When the counter has been set to the number of strokes where the master injector will flow exactly 132 cc, take two additional readings to insure repeatability. The comparator is now considered to be calibrated. Do not alter this counter setting and proceed to flow test each injector.

12-12. INJECTOR SPRAY PATTERN CHECK PROCEDURE (FIG 12-12).

a. Locate the spray test fixture (ST668) on or near the injector test stand (ST790), or another source of 50 PSI constant fuel pressure, so injector inlet connection of the test stand will reach the injector to be spray checked.

b. Attach drain hose to fixture base and place loose end in the test stand drain pan.

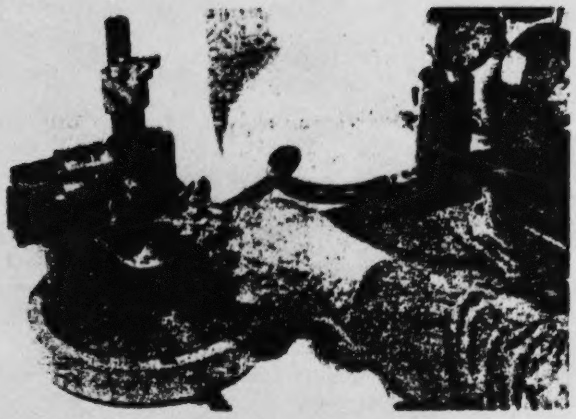

Figure 12-12. Spray pattern check procedure.

c. Assemble the cup seal spacer to seat bracket bore (H-2 seat). Place seat H-2 in seat bracket bore.

d. Check cup markings for number of spray holes and place applicable target ring in base of fixture. The NHC 250 engine will have eight holes which will be marked as the "target handle."

e. Insert injector into the adapter (ST1058) and remove the plunger assembly and spring from the injector.

f. Install plunger bore plug and seal to protect injector from dirt and damage.

g. Install the solid knurled plug in the drain opening adapter (ST1058).

h. Adjust holddown brackets with injector in fixture seat and tighten thumbscrew.

i. Tighten knob against plug and seal in plunger bore so it seals thoroughly.

j. Attach fuel inlet line from test stand to injector inlet of adapter.

k. Start test stand and set fuel pressure at 50 PSI.

l. Shift target ring in base of fixture so one of the spray streams hits center of No 1 or index window. This is the tallest window on the ring.

m. Each spray stream must hit a window in the target ring.

n. Each spray stream hits above, below, left, or right of a small window. Shift the target ring so No 1 window is at that stream. If the stream is still outside of No 1 window, the cup is defective or the spray hole is dirty. Clean spray holes with compressed air and recheck cup. If the spray pattern is still defective, check to make sure proper target ring is being used, or discard cup.

Note. - For a cup to be acceptable, no more than one stream must require the increased tolerance of the No 1 window.

o. After spray testing, assemble plunger with spring in adapter and store in a clean place until ready for flow test.

SECTION XIII. CALIBRATION OF CUMMINS PTG FUEL PUMP

13-1. GENERAL. When testing the PTG pump, fuel delivery is not measured in the burettes of the 10 hp test stand. Instead the total output volume of the pump is routed through the auxiliary flow panel (fig 13-1). Fuel quantities are indicated by a float, while the variable pump pressures and vacuum are shown on corresponding gages. The test stand fuel supply pump is not utilized when calibrating PTG pumps.

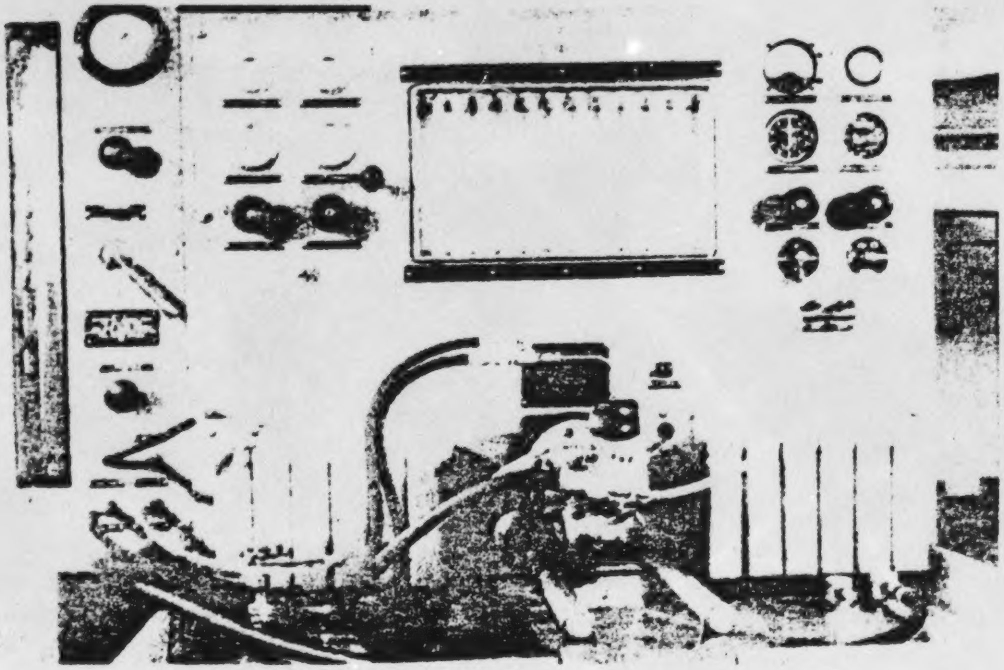

Figure 13-1. Test stand with flow panel.

13-2. AUXILIARY FLOW PANEL.

a. The flow panel may be attached to either side of the test stand (fig 13-2).

b. Fuel readings are taken by observing the relative position of a float device within the rotameter. A graduated glass tube shows a range of 1.0 to 10.0 x 100 (times one hundred) in PPH (pounds per hour). The fuel pressure gage with flow control valve or pressure regulator ranges from 0 to 300 PSI. A four-way selector valve allows routing of fuel when conducting a specific test. The three valve positions for normal pump testing are from left to right: rotameter, leakage test, and idle. Other control and connection points are a bypass valve, a pressure gage outlet, fuel input, fuel outlet, and leakage test outlet fittings. The complete auxiliary flow panel modification kit is listed under FSN 4910-763-7495.

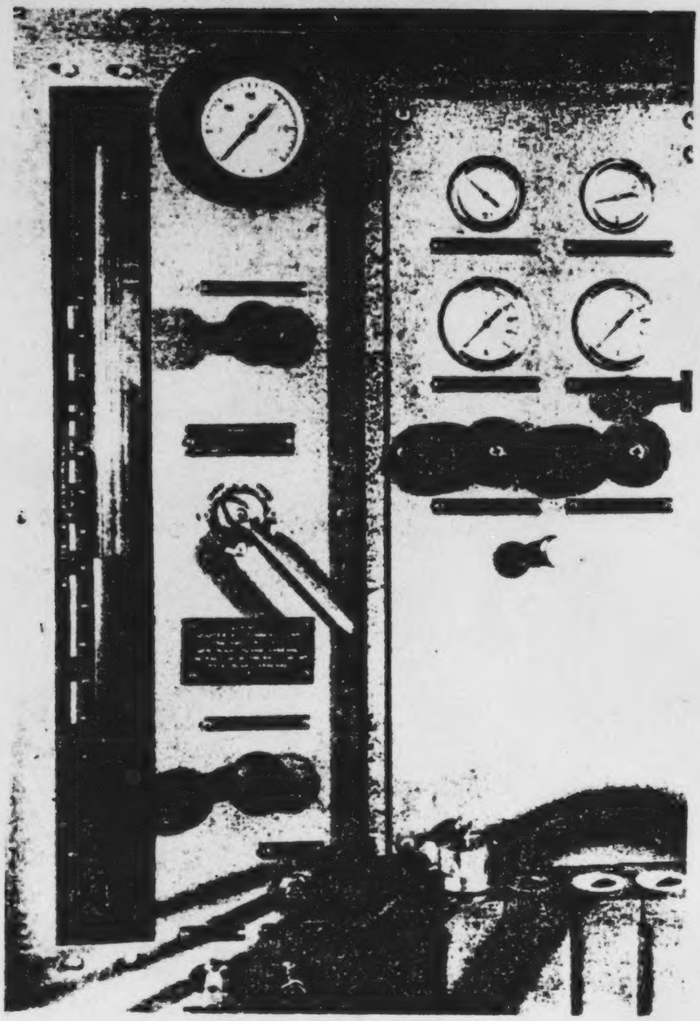

Figure 13-2. Flow panel.

13-3. PUMP MOUNTING.

a. Bracket and hardware.

(1) Mount adapter ring ("top" mark) to adapter bracket.

(2) Flange-fit and secure pump to bracket assembly.

(3) Place assembly on test stand rails and slide toward drive coupler.

Note. - A special stand drive shaft coupler and star wheel must be used.

(4) Aline and engage pump to shaft coupler and (allow for 1/16" clearance) tighten clamp bar.

b. Hose connections.

(1) Install pump inlet adapter and/or suction valve at gear pump inlet.

(2) Connect No 8 hose from test stand fuel outlet/suction valve to pump inlet adapter.

(3) Connect vacuum gage to small flare connector at pump inlet adapter.

(4) Connect dual line from pressure gage auxiliary panel to pump outlet fitting at solenoid.

(5) Connect No 8 hose from flow panel fuel outlet to test stand fuel return.

(6) Connect No 4 hose (plastic) from pump cooling port to flow panel auxiliary fuel inlet.

(7) Install nozzle adapter in accumulator chamber nearest to flow panel and connect line from leakage test outlet.

13-4. TEST AND CALIBRATION. Tests on the PTG pump are divided into the following steps:

a. Gear pump suction test.

Note. - Do not turn on auxiliary motor switch during tests.

(1) With main power switch closed, turn on fuel heater (80° to 100° F).

(2) Range selector to HIGH.

(3) Direction of rotation REVERSE.

(4) Open bypass valve, suction valve, and flow control valve.

(5) Selector valve to ROTAMETER.

(6) Throttle to full forward.

(7) Start test stand and operate at 450 to 500 RPM.

(8) Observe fuel flow in flow meter. If air bubbles are present, move throttle between full fuel and idle position. If bubbling persists, check for air leaks.

(a) Check all lines and connections.

(b) Apply lubricant to weep hole at pump drive cover and tachometer drive to detect leaks.

(9) With speed at 500 RPM, slowly close suction valve until 15 inches Hg is indicated on vacuum gage. A lower reading indicates leaks or defective gear pump.

b. Vacuum adjustment (fig 13-3).

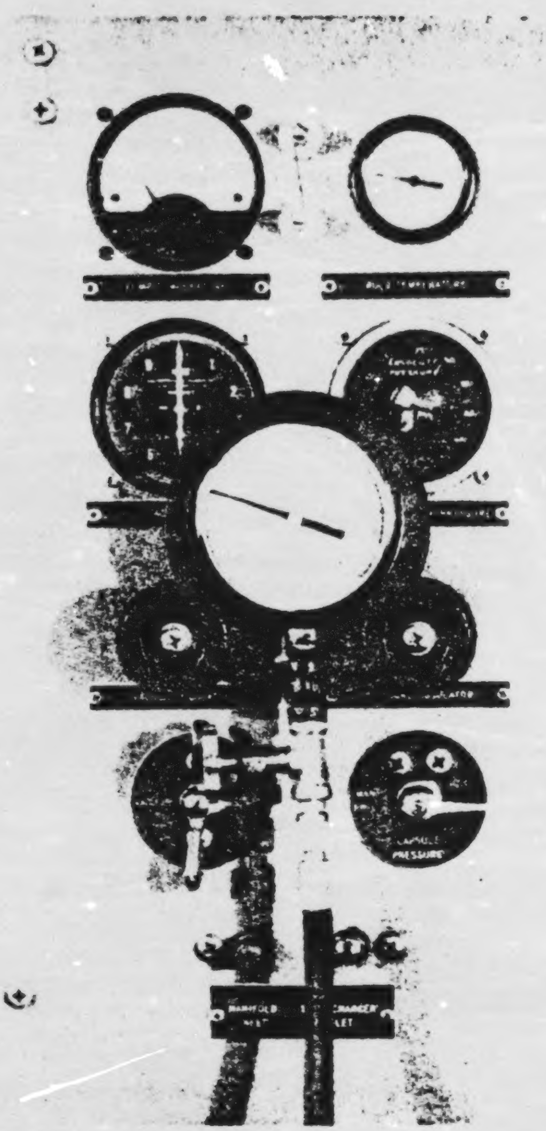
CAPSULE PRESSURE
MANIFOLD
CHARGER

Figure 13-3. Suction valve vacuum setting.

(1) Close bypass valve.

(2) Open suction valve and fuel flow valve.

(3) Increase speed to 2,000 RPM.

(4) Slowly close suction valve until 8 inches Hg is indicated on vacuum gage.

Note. - Suction valve will remain in this position for all further tests since the pump is calibrated with a simulated fuel filter restriction of 8" Hg.

c. Total fuel flow.

(1) Increase pump speed to rated 2,100 RPM.

(2) Gradually close fuel flow control valve until the flow meter indicates 340 lb-hr at 171 to 176 PSI manifold pressure.

(3) Reading is taken at lower edge of float cone. Multiply face value by 100 for correct reading,

(4) If fuel pressure does not fall within tolerance range of 171 to 176 PSI with rated flow of 340 lb-hr, remove throttle shaft restriction plunger. Remove shims to increase pressure. Set pressure from 3 to 6 PSI above maximum (176 + 3 to 6).

Note. - Rear throttle screw is used for final adjustment.

d. Governor cutoff RPM.

(1) With all controls in the same position, increase pump speed until fuel pressure just begins to drop. This should take place at 2,130 to 2,150 RPM.

(2) Add shims at governor high speed spring (outer spring pack) to raise speed. Each 0.001-in shim = 2 RPM.

(3) Increase test stand speed until fuel pressure drops to 40 PSI. This should take place at 2,300 RPM.

e. Checkpoint two.

(1) Lower speed to 1,400 RPM and check for 220 lb-hr at 91 to 97 lb fuel pressure. Compensate by adjusting flow control valve.

(2) If not within specifications, the governor plunger and/or weight assist plunger is defective.

f. Weight assist pressure.

(1) Check for low speed torque.

(2) At 800 RPM, check for 35 to 41 PSI with 120 lb-hr of fuel flow. Compensate with flow control valve.

(3) Add shims under weight assist plunger to raise pressure. Pump must be recalibrated.

g. Throttle leakage test.

(1) Reduce speed to 500 RPM.

(2) Turn selector valve to leakage test position.

Note. - Open bypass valve.

(3) Set test stand count selector to 1,000.

(4) Increase speed to 2,100 RPM and move throttle to idle position.

(5) Push START COUNT button and observe fuel collection in burette.

(6) Repeat count; delivery per count should be 15 to 17 cc.

(7) Adjust front throttle screw in to increase delivery.

(8) Monitor pump temperature. To avoid excessive heat, move throttle to full fuel position to allow circulation of fuel.

h. Idle fuel pressure.

(1) Reduce speed to 500 RPM.

(2) Close bypass valve.

(3) Turn selector valve to IDLE position.

(4) With throttle at idle position, fuel pressure should indicate 26 PSI.

(5) To increase pressure, remove pipe plug in spring pack cover and turn idle screw clockwise with special tool (ST).

i. Pump removal.

(1) Shut down test stand.

(2) Drain and remove pump.

(3) Seal all openings.

Note. - When mounting the pump on an engine, slight adjustments of manifold pressure and idle pressure can be made. However, a correction of more than 5 PSI manifold pressure calls for calibration of the pump assembly.

13-5. CALIBRATION OF PTG PUMP WITH MVS GOVERNOR MOUNTED.

a. Move both throttle levers to full fuel position.

b. Back out maximum speed screw (top screw).

c. Set suction restriction to 8-in Hg at 2,000 RPM.

d. Adjust fuel flow at rated RPM to specific 2,100 RPM; 340 lb-hr at 171 to 176 PSI.

e. Check automotive governor setting by increasing RPM until fuel pressure drops (2,120-2,140 RPM). Make correction at governor high speed spring.

f. Adjust MVS governor after setting automotive governor as follows:

(1) Operate pump at maximum rated speed.

(2) Turn maximum speed screw (top screw) of MVS governor in until manifold pressure starts to drop.

(3) From this point, one turn out will be required to set the MVS governor slightly above the automotive governor.

g. Make idle adjustment with MVS governor as follows:

(1) With throttle shaft in idle position, check for 26 PSI fuel pressure at 500 RPM. Adjust idle pressure in spring pack housing.

(2) With automotive idle adjusted, move throttle shaft to full fuel position and:

(a) Move MVS throttle to idle position.

(b) Adjust idle screw (rear) to 26 PSI fuel pressure.

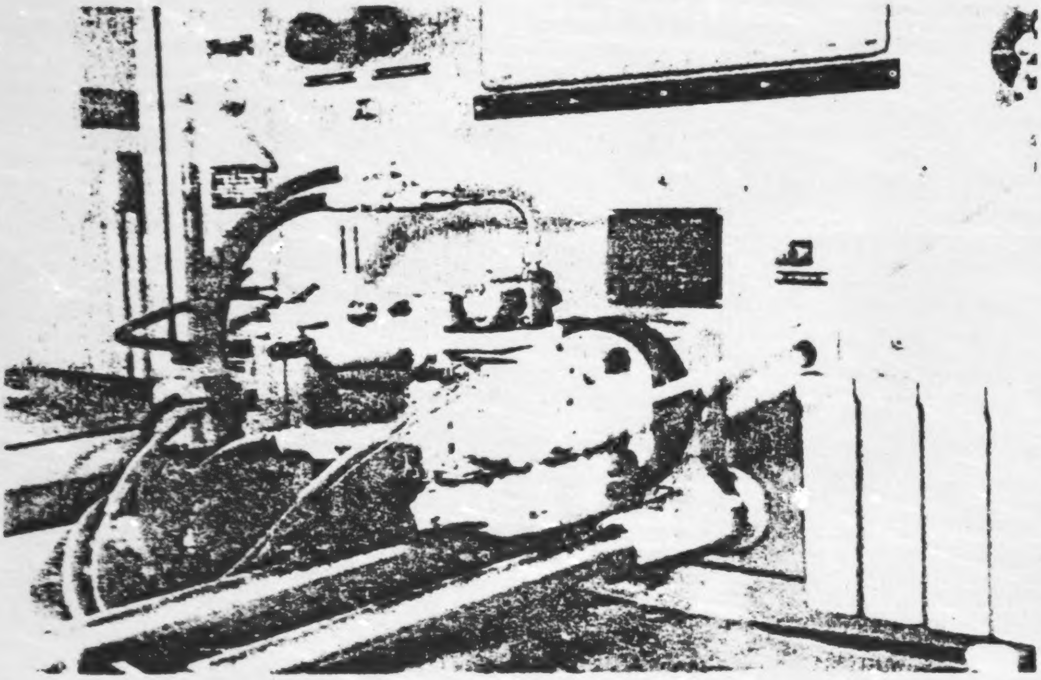

Figure 13-4. Testing PTG pump with MVS governor.

APPENDIX

REFERENCES

TM 9-2320-260-34, Direct and General Support Maintenance Manual: Truck Chassis, 5 Ton, 6x6, M809, June 1970.

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TM 9-2910-200-35, Field and Depot Maintenance Manual for Pumps, Injectors, Field Assemblies (Simmonds Models SU-15 and SU-570), December 1959.

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TM 9-4910-409-12, Operator and Organizational Maintenance Manual: Tester Fuel Injector Nozzle, October 1963.

Handbook of Operation and Service Instructions AD 369—Simmonds Aeroscessories, Inc, Tarrytown, New York.

Field Service Bulletin No 193—Description of Fuel Injection System Used on Continental Model AVSI 1790-6, Engine, Continental Motors Corporation, Muskegan, Michigan, August 1954.

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EXERCISE RESPONSE LIST

SUBCOURSE 403
PRINCIPLES OF FUELS AND FUEL SYSTEMS

JULY 1975

8-4

DEPARTMENT OF ARMY WIDE TRAINING SUPPORT
US ARMY ORDNANCE CENTER AND SCHOOL
ABERDEEN PROVING GROUND, MARYLAND

NOTICE

The inclosed responses are listed in numerical order. After making a circle around the number of your choice on the ANSWER SHEET, check the same number on the exercise response list. If you selected the correct answer, the response will indicate it with the word "CORRECT" appearing as the first word. Read the response for further information and then proceed to the next question. If the response shows you have not selected the correct choice, read the information presented to find out why your choice was wrong and where you can find the correct answer. The suggested references are designed to cover major teaching points in each lesson, thus reinforcing the student's learning process.

REMINDER!! Be sure to PRINT your name, grade, social security account number, subcourse number, and date in the top left corner of your answer sheet before you start your first exercise.

RESPONSE NUMBER	RESPONSE*
100	CORRECT. The water jacketed intake manifold maintains the temperature of the air entering the cylinders at 150° F even in cold climates.
101	Para [illegible] 8 1
103	Para 7b
104	Para 1a
109	CORRECT. A small and short intake manifold will retain the air velocity for good fuel distribution.
110	Para 2a
112	CORRECT. The heating of a liquid will aid in the movement of the molecules into the air.
113	Para 2c(2)
116	Para 2g(1)
117	CORRECT. This is always a good test method to use when checking continuity.
119	Para 7c
122	Para 5b(1)
124	Para [illegible] 2a
129	CORRECT. A spring moves the plunger down if it has been raised by the vacuum.
133	Para 2~~b~~ d
134	CORRECT. Any problem such as leaks, restrictions, or dirt that causes the oil pressure to drop below 28 PSI will cause poor engine idling.
136	CORRECT. The rotating generators receive the hot exhaust gases from the turbine and cool the gases as they pass through them.
138	ST 9-177, para 3-2c(2)
141	Para 5a
143	Para 3b

*If your response is not listed CORRECT, check the indicated reference for the proper answer.

145 ST 9-177, para 3-2f(3)

147 ST 9-177, para 6-1b(1)

150 Para 6b

152 Para 2e

154 Para 6e(2)(c)

156 CORRECT. The function of the accelerating pump is to supply additional fuel when the throttle is suddenly opened.

161 CORRECT. The power stroke of a 4-stroke-cycle engine is longer because the exhaust valves stay closed longer.

164 ST 9-177, para 3-2f(3)

166 Para 2a

167 CORRECT. Injection components require fuel that is free from all foreign material.

170 Para 1f

173 Para 5a(3)

175 Para 5b(8)

177 CORRECT. The fuel-air mixture is diluted by a high percentage of inert exhaust gases at engine idling speeds.

178 Para 7c

179 CORRECT. This is the pressure that is applied to the fuel in the float bowl.

184 CORRECT. The logistical problems plus the fact that gasoline engines operate only on high octane fuel—for which there is no suitable substitute.

188 CORRECT. The spring closes the poppet on the valve in the circuit.

191 CORRECT. When air is passing through the venturi it creates the pressure difference, causing fuel to discharge from the fuel nozzle.

192 Para 3c (3)

194 ST 9-177, para 7-5h

195 CORRECT. It would be very difficult to achieve a uniform rate of fuel injection using this method.

197 Para 3b

200 CORRECT. The maximum package weight is 6 pounds per horsepower.

204 CORRECT. The choke valve is placed above the venturi, so when it is closed it will create a high-pressure difference at cranking speeds.

205 ST 9-177, para 3-3e(1)

206 CORRECT. The valve opening is not affected under these conditions.

207 ST 9-177, para ~~2~~3-2a(3)(e)

210 CORRECT. The fuel is sprayed in the chamber in the direction of the air swirl.

213 CORRECT. A reading in ohms of any number from 25 to 32 indicates the field coils are serviceable.

215 Para 2f

218 ST 9-177, para 3-2f(3)

220 Para 5a(2)

223 Para 1c

225 Para 6e(2)(d)

227 CORRECT. If you check table I you will find the AVSI 1790-6 engine uses this model of the Simmonds pump.

228 Para 3h(1)

231 Para 4c

233 CORRECT. The camshaft operates the overhead valves and push rods from a gear that is part of the helical gear train and located at the fan end of the engine.

235 CORRECT. This would be the approximate temperature for igniting a homogeneous fuel-air mixture under still conditions.

236 CORRECT. Atmospheric pressure on the fuel will force it from the bowl when a partial vacuum is created at the outlet nozzle.

239 ST 9-177, para 4-3f(1)

241 Para 1c

242	Para 2c
243	Para 1c
245	Para 5a(4)
248	CORRECT. When an electric fuel pump is used on a vehicle it normally is placed in the fuel tank.
253	Para 2d(3)
256	Para 3c
259	CORRECT. The stepped end of the metering rod fits in the high speed jet. When the rod is raised, more fuel enters the high speed circuit.
260	Para 2c
264	Para 3c(3)
268	CORRECT. With a metering valve hanging open, the engine will pop under load conditions caused by a lean mixture.
271	Para 5b(7)
274	Para 2e(2)
276	Para 7d
277	Para 2b
278	Para 2e
279	Para 2d(3)
282	CORRECT. Jets spray oil on the underside of the pistons to aid in the cooling process when the engine is operating.
284	ST 9-177, para 2-3b(1)
288	Para ~~1~~2d(4)
289	Para 4c
290	Para 3a
292	Para 2c
293	Para 2d
295	Para 2e
296	CORRECT. When the spring is heated it opens the valve and, as it cools, it closes the valve.

298	Para 2d(3)
299	CORRECT. The air bleed allows air to enter the fuel circuit where it helps to atomize the fuel.
304	ST 9-177, ~~para~~ Table 5-1
307	Para 2a(4)
309	CORRECT. This is the temperature at which thermal cracking of crude oil is accomplished.
311	ST 9-177, para 4-3b(2)(b)
313	Para 5a(2)
316	CORRECT. A leak in the manifold line will allow additional fuel to enter and mix with the air-fuel mixture, resulting in a rich mixture.
320	CORRECT. The skew shaft is a machined mechanite casting containing self-lubricating properties.
323	ST 9-177, para 4-3f(1)
324	CORRECT. A metering rod is used in some carburetors instead of the power jet.
326	Para 2d
330	Para 2d(4)
333	Para 2e(3)
336	CORRECT. This happens in a carburetor when the globules of gasoline mix with air.
339	Para 5b(4)
341	Para 2d
342	CORRECT. The iso-octane has a great resistance to detonation before ignition takes place at the proper spark setting.
344	Para 5a(4)
347	Para 2e(2)
349	Para 2e(2)
350	ST 9-177, para 5-3c
352	Para 6e(2)(i)
356	CORRECT. The air moving through the air horn creates the pressure differential that opens the off center choke valve.

358 CORRECT. The atmospheric pressure moves the piston cylinder against the spring tension.

360 Para 5b

362 CORRECT. An impeller is essential for proper distribution of the fuel in a radial engine.

363 Para 6e(2)(c)

365 Para 5b(1)

367 ST 9-177, para 2-3b(1)

369 CORRECT. Soft steel is used because of the pressures caused by the injection of fuels.

372 Para 5a

375 CORRECT. The percentage of hydrogen content to carbon determines the potential heat energy per unit. The greater the hydrogen content of hydrocarbon molecules, the greater the heat potential.

376 ST 9-177, para 3-3e(1)

378 Para 9f

379 Para 2d(3)

382 Para 7d

385 Para 1f

389 ST 9-177, para 6-1b(1)

390 Para 3b

391 Para 9e

392 Para 2c(2)

393 CORRECT. It is difficult to obtain maximum economy in an engine because of incomplete mixing of fuel and air under the various loads and speeds.

394 Para 2b

396 Para 5c

397 Para 2c(3)

400 Para 6e(2)(i)

402 CORRECT. The valve is controlled by pressure differences to reduce the amount of fuel flow in relation to the reduced airflow.

403 ST 9-177, para 7-5a

405 Para 5a(4)

407 CORRECT. The supercharger requires additional power to operate; therefore, more fuel is required for operation of the engine.

408 CORRECT. When the throttle is closed, a restriction or small opening is created. This creates a high vacuum below the throttle valve.

409 Para 5b

412 Para 2d

415 ST 9-177, para 3-2f(3)

416 CORRECT. This must be done so the proper ratio of air and fuel is delivered to the engine for all speeds and operating conditions.

417 CORRECT. To compensate for the increase in temperature in the cylinder head, heat exchangers or sodium-filled valves are used.

420 Para 3a

421 Para 1c

422 CORRECT. More air is packed into each cylinder with a supercharger. Remember, the greater the pressure at the beginning of a compressor's stroke, the greater the pressure at the end of the stroke.

423 CORRECT. This condition will cause a rich mixture to enter the engine; therefore, more fuel will be used.

425 ST 9-177, fig 5-25

426 CORRECT. More air is forced into the cylinders and this produces a more constant fuel-air ratio, which increases engine power.

427 CORRECT. This is created during the refining of crude oil.

429 CORRECT. The undesirable effects, chargeable to detonation, are always factors to consider.

432 Para 3b

434 Para 6b

437 CORRECT. The dry pump depends on a pocket of air while the wet pump has a spring; when the compressed air or spring expands, the fuel continues to flow.

440 Para 5b

442 ST 9-177, table ~~3~~ 5-1

444 CORRECT. This fuel is first ignited and it, in turn, ignites the main charge.

448 CORRECT. The military required an engine that would use most types of fuel to help overcome fuel problems in areas of operation.

452 CORRECT. The venturi creates a partial vacuum (or low-pressure area) at the outlet of the nozzle.

457 Para 2g

460 CORRECT. The temperature of the compressed air is the determining factor for any diesel engine to ignite.

463 Para 3b

465 Para 2g(2)

468 ST 9-177, para 5-4~~f~~e

471 Para 2d

474 Para 6e(2)(d)

477 ST 9-177, para 2-2c

482 Para 2f

483 Para 1c

485 CORRECT. The vacuum booster pump assists or helps keep the windshield wipers operating during periods when the manifold vacuum is low.

486 Para 2a

488 CORRECT. The fuel density compensator is an integral component of the injector pump assembly.

490 Para 8l

491 Para 2c(2)

492 Para 2c

493 Para 2g(1)

496 Para 2h(2)

497 ST 9-177, para 7-5f

498	CORRECT. The combustion chamber injection is more effective during extremely high speeds.
500	Para 2d(3)
501	CORRECT. Carbon and hydrogen combined in other proper chemical elements will burn freely.
504	ST 9-177, para 3-2d
505	ST 9-177, para 4-3b(2)(b)
508	ST 9-177, para 3-2c(2)
510	Para 7d
516	Para 2b(1)
520	ST 9-177, para 4-3b(3)
521	Para 9e
522	Para 2c(3)
523	Para 2e(3)
524	Para 7d
526	Para 5b(4)
527	CORRECT. A catalyst used in this process breaks down some of the chemicals into usable fuels.
529	Para 7b
531	Para 5a(4)
533	CORRECT. The fuel consumption is higher with a supercharged engine—so it is more costly to operate.
536	Para 1a
537	Para 3c
539	CORRECT. Hot air from the exhaust manifold is directed onto the thermostatic spring.
541	CORRECT. You may find a fuel filter located near the tank or near the carburetor. The fuel must be filtered before it enters the carburetor.
545	CORRECT. The volume is reduced one-half if the pressure is doubled.
547	Para 4b
549	Para 5a(1)

553 ST 9-177, para 7-5h

555 Para 2a(4)

559 CORRECT. The burning of fuel only, as it evaporates, prevents the knocking normally caused by low octane gasoline.

562 CORRECT. A less volatile fuel will wash the oil seal from the cylinder walls and dilute the oil in the crankcase.

563 Para 2c(2)

565 Para 5b(7)

567 Para 2c

570 ST 9-177, para 2-2c

572 Para 2e(2)

573 CORRECT. You do this so the openings in the top and body will aline when assembling the pump.

575 CORRECT. The gas turbine engine can operate on a wide range of fuels and maintain high torque at stall speeds.

577 Para 2c

578 CORRECT. The motor method test conditions are more severe and give truer results.

579 Para 3b

580 CORRECT. A centrifugal supercharger is a nonpositive, displacement-type pump.

581 CORRECT. The main nozzle is positioned in the venturi and is part of the high speed circuit.

582 CORRECT. If a fuel tank is positioned high enough, gravity will send the fuel to the carburetor so no pump will be needed.

584 Para 2g(2)

590 CORRECT. There is an outer and inner smaller spring that does the regulating.

591 Para 2g

594 Para 2e

595 Para 1c

597 CORRECT. If a positive-type pump was used to supply fuel to a carburetor, a bypass line would be necessary to take care of excess fuel when the carburetor bowl was full.

600 CORRECT. These components are constructed to withstand the pressures developed by high combustion pressures.

603 ST 9-177, para 4-3c(2)

608 Para 3h(1)

612 Para 2a

615 ST 9-177, para 3-2d

617 Para 2d(3)

621 ST 9-177, para 4-3c(2)

624 CORRECT. Compression ignition engines have a higher compression ratio than spark ignition engines because the compressed air produces enough heat to ignite the fuel-air mixture.

627 Para 2g

628 Para 9f

629 ST 9-177, para 4-3b(3)

630 CORRECT. These are added to prevent the formation of gum deposits in the fuel system components.

631 ST 9-177, para 5-3c

634 CORRECT. The dual carburetor is so designed that the throttle valves are mounted on a single shaft.

635 Para 5b

636 Para 5c

637 Para 2d

638 ST 9-177, para 7-5a

639 CORRECT. This is to hold the fuel in the accelerating pump cylinder until it is discharged.

642 Para 2d

643 Para 2g

647 CORRECT. Excess fuel will be flowing into the system; therefore, the fuel consumption will be high.

648 ST 9-177, para ~~2~~3-2a(3)(~~b~~a)

651 CORRECT. The compressed air pressing through the rotating regenerators is heated by the regenerators.

657 CORRECT. Gasoline is readily vaporized when heated and will be one of the first products released when distilling crude oil.

661 CORRECT. These chemical properties of gasoline tend to oxidize, which causes gums to form in fuel system components.

662 Para 2d(3)

665 Para 5a(1)

669 ST 9-177, para 5-4e

672 CORRECT. The heated compressed air enters the combustors where the injected fuel is ignited.

674 Para 2b(1)

677 ST 9-177, para 5-25

679 Para 2d(3)

682 CORRECT. Also included would be free-piston engines. Turbines are expected to approach diesel engine fuel economy at part and full load.

684 Para 5b(8)

685 Para 4b

688 Para 5a(3)

690 Para 2a

691 CORRECT. This is the circuit that provides the fuel to keep an engine operating while the vehicle is parked.

694 ST 9-177, para 7-5f

696 CORRECT. The "controlled evaporation" principle is the process developed by Dr. Meurer. This process is sometimes called hypercycle.

699 Para 2h(2)

ANSWER SHEET

1-9
SSAN

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10

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11-17
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FOR KEYPUNCH ONLY

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18-21
FIRST FOUR LAST NAME

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ATTENTION STUDENT: Fill in 1 thru 9 and 18 thru 21 only.

NOTICE

Refer to the instructions preceding lesson exercise question 1 in your study text for information on the use of this answer sheet and the exercise response list. After your selections of choices for all exercise questions have been circled, tear this sheet out of the subcourse, fold it as instructed on the address side, and mail it to the school.

	a	b	c		a	b	c		a	b	c		a	b	c		a	b	c
1.	104	501	536	41.	437	523	333	81.	245	405	460	121.	625	346	515	161.	428	613	114
2.	223	657	595	42.	349	639	274	82.	360	440	624	122.	484	255	399	162.	201	552	443
3.	421	309	243	43.	277	394	647	83.	600	366	122	123.	217	698	436	163.	509	373	660
4.	241	483	527	44.	539	496	699	84.	233	526	339	124.	334	503	139	164.	180	481	230
5.	375	166	612	45.	113	408	392	85.	565	282	271	125.	593	388	291	165.	357	272	554
6.	690	110	427	46.	522	397	299	86.	175	684	488	126.	111	650	331	166.	586	386	174
7.	562	290	420	47.	191	642	412	87.	434	150	575	127.	633	252	479	167.	343	151	686
8.	630	197	463	48.	358	662	253	88.	651	363	164	128.	216	438	528	168.	120	519	496
9.	579	143	661	49.	500	379	416	89.	225	474	672	129.	411	196	671	169.	628	246	314
10.	547	685	342	50.	116	493	204	90.	400	138	352	130.	558	169	398	170.	487	652	203
11.	289	578	231	51.	164	415	533	91.	371	535	202	131.	368	697	275	171.	285	433	540
12.	635	409	235	52.	629	195	520	92.	513	266	446	132.	144	467	656	172.	618	155	361
13.	429	396	636	53.	311	505	498	93.	106	654	543	133.	476	502	123	173.	473	650	249
14.	103	112	529	54.	167	239	323	94.	644	262	454	134.	602	258	450	174.	211	566	489
15.	119	336	178	55.	304	442	227	95.	387	518	181	135.	229	303	598	175.	182	351	681
16.	610	276	452	56.	631	350	590	96.	169	374	605	136.	168	441	305	176.	308	466	588
17.	238	382	524	57.	677	206	425	97.	557	127	332	137.	472	680	125	177.	538	265	105
18.	101	490	362	58.	389	402	147	98.	410	619	212	138.	359	157	576	178.	445	187	646
19.	521	391	369	59.	316	638	403	99.	247	461	587	139.	534	380	244	179.	153	542	312
20.	628	378	426	60.	194	563	268	100.	328	551	186	140.	675	221	401	180.	234	655	458
21.	486	124	582	61.	393	570	477	101.	199	301	614	141.	287	589	606	181.	670	283	550
22.	541	492	242	62.	284	367	109	102.	693	131	459	142.	354	696	189	182.	302	430	148
23.	326	133	597	63.	207	545	648	103.	431	607	250	143.	641	297	499	183.	574	317	240
24.	293	485	637	64.	422	138	508	104.	281	480	512	144.	163	566	386	184.	165	345	584
25.	248	330	298	65.	615	504	417	105.	561	298	318	145.	546	322	287	185.	325	663	261
26.	152	295	423	66.	145	407	218	106.	115	507	238	146.	228	449	514	186.	622	178	406
27.	296	591	643	67.	580	205	378	107.	601	222	419	147.	418	130	609	187.	602	269	618
28.	573	390	432	68.	621	177	603	108.	414	190	650	148.	506	395	196	188.	208	617	327
29.	537	213	256	69.	468	689	320	109.	356	611	172	149.	294	604	406	189.	686	413	107
30.	192	284	117	70.	134	497	694	110.	687	439	329	150.	424	158	353	190.	377	673	132
31.	581	471	341	71.	385	448	170	111.	140	381	569	151.	645	219	548	191.	135	319	461
32.	279	617	324	72.	200	555	307	112.	384	667	193	152.	128	583	264	192.	683	185	370
33.	691	577	292	73.	674	184	516	113.	610	118	556	153.	321	453	676	193.	494	251	525
34.	269	679	298	74.	567	260	682	114.	149	447	209	154.	171	364	620	194.	544	469	232
35.	347	572	129	75.	228	608	161	115.	462	335	623	155.	653	237	464	195.	267	530	649
36.	158	604	278	76.	372	141	696	116.	338	666	404	156.	435	692	146	196.	668	263	455
37.	179	663	491	77.	649	665	210	117.	108	224	300	157.	660	102	337	197.	315	160	632
38.	465	584	188	78.	444	220	313	118.	599	664	142	158.	310	532	270	198.	137	511	340
39.	215	634	482	79.	688	559	173	119.	306	121	640	159.	214	475	571	199.	568	383	280
40.	457	627	356	80.	100	344	531	120.	183	470	273	160.	678	162	348	200.	478	689	126

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CORRESPONDENCE COURSE
# of the
US ARMY ORDNANCE
CENTER AND SCHOOL

EXAMINATION

Ordnance Subcourse No 403	Principles of Fuels and Fuel Systems
Credit Hours.	One
Objective	To test your knowledge of all material studied in this subcourse.
Suggestions	Before starting this examination, it is suggested that you review all lessons studied in this subcourse.
Study Assignments	ST 9-177; all study texts used in this subcourse.
Materials Required	Answer sheet

(Do not send these pages in—use the answer sheet provided for recording and mailing your solution.)

Requirement—40 Questions—Weight 100—All items are weighted equally.

MULTIPLE CHOICE

(See instructions on answer sheet provided)

1. What characteristic of carbureted air-fuel systems is the MOST undesirable in tactical situations?

   a. Icing
   b. Excessive warmup time
   c. Inability to operate in all positions
   b. Backfiring

2. What is taking place when the molecules of a liquid move from the liquid into the air?

   a. Condensation
   b. Evaporation
   c. Atomization
   d. Aeration

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3. What type compressor pump is MOST suitable for gas turbine engines?

   a. Axial flow
   b. Root's blower
   c. Centrifugal vane
   d. Sliding vane

4. The definition of volatility is "The ease with which the fuel is

   a. mixed with air for burning."
   b. atomized under pressure."
   c. vaporized under prescribed conditions."
   d. stabilized under heat."

5. What is generally established as the best air-fuel ratio in a gasoline engine?

   a. 12:1
   b. 13:1
   c. 14:1
   d. 15:1

6. When overhauling a carburetor, which components must be installed as a matched set?

   a. Float needle valve and seat
   b. Accleration pump piston and cylinder
   c. Metering rod and jet
   d. Step-up piston and cylinder

7. The Simmonds injector pump will deliver the MOST fuel when the

   a. capsule is expanded.
   b. skew shaft is high.
   c. skew shaft is low.
   d. plunger stroke is short.

8. How would fuel injected engine operation be affected if the skew shaft of the injector pump were sticking?

   a. Mixture would be too lean during idling
   b. Engine acceleration would be poor
   c. High pressure oil would stop circulating through pump
   d. Wobble plate would stop oscillating

9. To check the resistance in the armature windings of a 24-volt fuel pump, the test meter leads are connected to alternate commutator bars. How many ohms of resistance should the meter indicate if the windings are satisfactory?

   a. 0.70 to 1.00
   b. 1.35 to 1.7
   c. 3.0 to 3.85
   d. 5.4 to 7.0

10. **The greatest volume of fuel-air mixture will enter the intake manifold of an engine when the**
    - a. **throttle valve is parallel to airflow.**
    - b. **throttle valve is perpendicular to airflow.**
    - c. **choke valve is closed.**
    - d. **metering rod is seated in its jet.**

11. The fuel pumps used on MOST vehicles with gasoline engines
    - a. are driven by a side gear on the distributor shaft.
    - b. operate on the nonpositive pump principle.
    - c. depend on gravity to feed fuel from the fuel tank.
    - d. operate on the positive pump principle.

12. Which statement regarding the air-fuel induction system of a carbureted engine is TRUE?
    - a. Fuel intake per cylinder is constant for all speeds
    - b. Fuel input is the major factor limiting engine power output
    - c. Air supply is the major factor limiting engine power output
    - d. Air velocity through the carburetor horn is constant at all speeds

13. What carburetor component aids in atomizing the fuel during idle speed operation?
    - a. Air bleed
    - b. Needle valve
    - c. Bowl vent
    - c. Main venturi

14. The accelerating pump circuits used in most carburetors
    - a. contain a venturi and air bleed.
    - b. direct high air pressure to top of float bowl.
    - c. supply extra fuel during high speed operations.
    - d. are operated mechanically by throttle linkage.

15. After the cover of a fuel pump with a vacuum pump assembly has been separated from the body, what is the next step in disassembly?
    - a. Move rocker arm and unhook links from diaphragm
    - b. Remove lower oil seal retainer
    - c. File off riveted end of pump rocker arm pin
    - d. Remove linkage and bushing from rocker arm

16. What is the greatest advantage in the use of multifuel engines as opposed to gasoline operated engines?
    - a. Greater horsepower can be achieved
    - b. Logistical costs in the transportation of fuel are reduced
    - c. Cross-country maneuverability is improved
    - d. Increased tactical applications due to reduced noise level

17. What is associated with rapid combustion and a high rate of pressure rise in a gasoline engine?

    a. Excess fuel consumption
    b. Loss of thermal efficiency
    c. Detonation
    d. Slow performance

18. How much resistance, in ohms, should exist in the field coil when testing a 24-volt electric fuel pump?

    a. 80 to 85
    b. 90 to 97
    c. 100 to 109
    d. 113 to 125

19. What action occurs in a multifuel engine that operates on the hypercycle principle?

    a. Slow evaporation produces a long burning time
    b. The fuel evaporates and ignites simultaneously with injection
    c. 95 percent of the fuel ignites on contact with combustion chamber
    d. A maximum of 5 percent of the fuel is injected into swirling air of the chamber

20. The amount of spring tension that tends to keep a carburetor automatic choke valve closed is determined by the

    a. intake manifold vacuum.
    b. volume of air passing through the horn.
    c. temperature of the engine.
    d. pressure applied on throttle linkage.

21. What must be done to a new diaphragm before it is installed in a mechanical fuel pump?

    a. Apply sealing compound to outer edges
    b. Soak it in clean kerosene
    c. Apply a coat of shellac to engine side
    d. Soak it in hot water

22. What condition exists when the throttle of a fuel injected gasoline engine is open past the idle or no-load position?

    a. The fuel air mixture is about 10:1
    b. Maximum power is developed
    c. The ignition phase is retarded
    d. Exhaust gas dilution is at its minimum

23. What statement, in reference to the LDS-465-1 multifuel engine, is TRUE?

    a. It operates on a 10:1 compression ratio
    b. Its crankshaft is designed to withstand 3,500 PSI firing pressures
    c. It operates on the principle of compression ignition
    d. It is designed as a short-stroke engine

24. One of the problems of carbureted air-fuel induction that does NOT exist in injection systems is that the fuel

    a. must be filtered extensively.
    b. may condense before reaching cylinder.
    c. vaporizes in the intake manifold.
    d. supply pressure must be high.

25. What are the two basic methods for rating fuels for automotive engines?

    a. Research and supercharge
    b. Motor and supercharge
    c. Motor and AN performance number
    d. Research and motor

26. What item is needed on the LDS-465-1 engine to keep the induction air warm during cold weather operation?

    a. Water jacketed manifold
    b. Off-vehicle heating kit
    c. Flame heater in the exhaust manifold
    d. Electric heater in the turbocharger

27. Which is an undesirable characteristic of diesel engines?

    a. Insufficient torque is developed at low speeds
    b. Excessive carbon monoxide is present in exhaust gases
    c. Starting is rather difficult
    d. The fuel does not ignite easily

28. What causes a gum formation in gasoline when it is exposed to high temperature during storage?

    a. Evaporation
    b. Oxidation
    c. Vaporization
    d. Condensation

29. What is a disadvantage of GMT-305 turbine engines?

    a. Engine weight in comparison to horsepower output is excessive
    b. Engines cannot maintain high torque at stall speeds
    c. Complicated cooling equipment is required to maintain acceptable temperatures
    d. Deceleration of the engine does not assist braking action of vehicle

30. Which item in the full-power circuit of a carburetor is controlled by the throttle valve linkage?

    a. Metering rod
    b. Power jet
    c. Vacuum step-up
    d. Air bleed

31. Repair of a grounded armature from an electric fuel pump should NOT be attempted because

    a. repair parts are not readily available.
    b. the armature is in dynamic balance and cannot be disassembled for repairs.
    c. the pressure required for disassembly is a safety hazard.
    d. the armature and field coils must be in matched sets.

32. What statement in relation to gases is CORRECT?

    a. Volume increases as the pressure applied increases
    b. Weight decreases as pressure applied decreases the volume
    c. Density increases as pressure applied increases
    d. Volume decreases proportionally with temperature increases

33. American diesel engines are classified according to the

    a. speed at which engine normally operates.
    b. number of cylinders.
    c. horsepower the engine develops.
    d. cetane number of fuel required for the engine.

34. Intake manifolds are built straight and short as possible in order to

    a. reduce ignition lag.
    b. lessen the chance of condensing the fuel.
    c. increase the fuel-to-air ratio.
    d. prevent engine backfire.

35. Which carburetor malfunction will cause poor gas mileage?

    a. Leak around the manifold gasket
    b. Worn leather on the acceleration pump piston
    c. Float level set too high
    d. Choke valve remaining in the full-open position

36. After the capscrews are removed from the mechanical fuel pump cover it can be separated from the main body by

    a. inserting a small screwdriver between the units and prying.
    b. securing body in a vise and removing cover with a wrench.
    c. tapping cover lightly with a wooden mallet.
    d. rotating cover in a counterclockwise direction.

37. Which vapors are separated first when crude oil is distilled?

    a. Natural gasoline
    b. Kerosene
    c. Diesel oil
    d. Straight-run gasoline

38. What type engine is considered to be a true multifuel engine?

a. Diesel
b. Gasoline
c. Gas turbine
d. Wankel

39. What type combustion chamber is found on 2-stroke-cycle diesel engines?

a. Precombustion
b. Turbulence
c. Divided
d. Open

40. What is a common cause of preignition in the gasoline engine?

a. Late timing
b. Hot exhaust valves
c. High octane fuel
d. Cold intake valves